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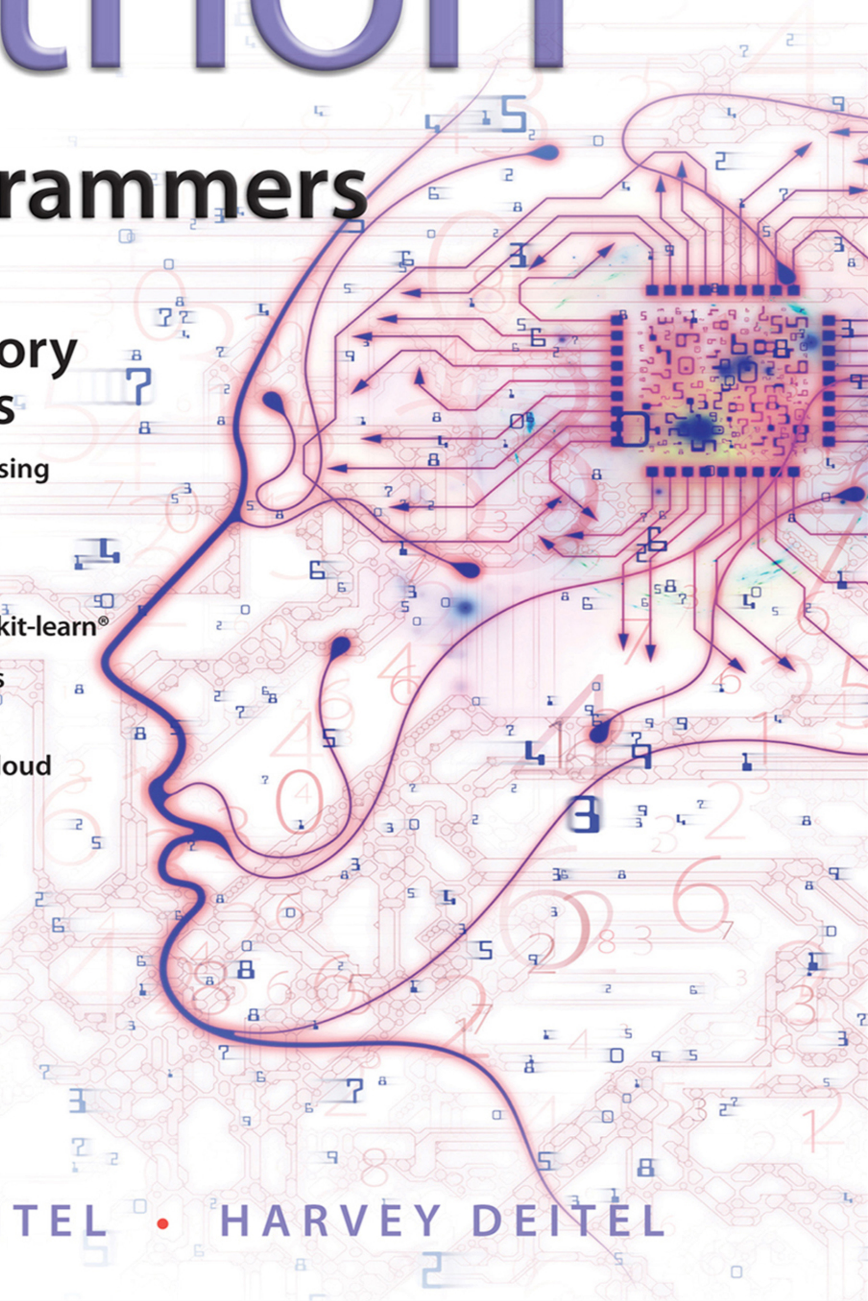

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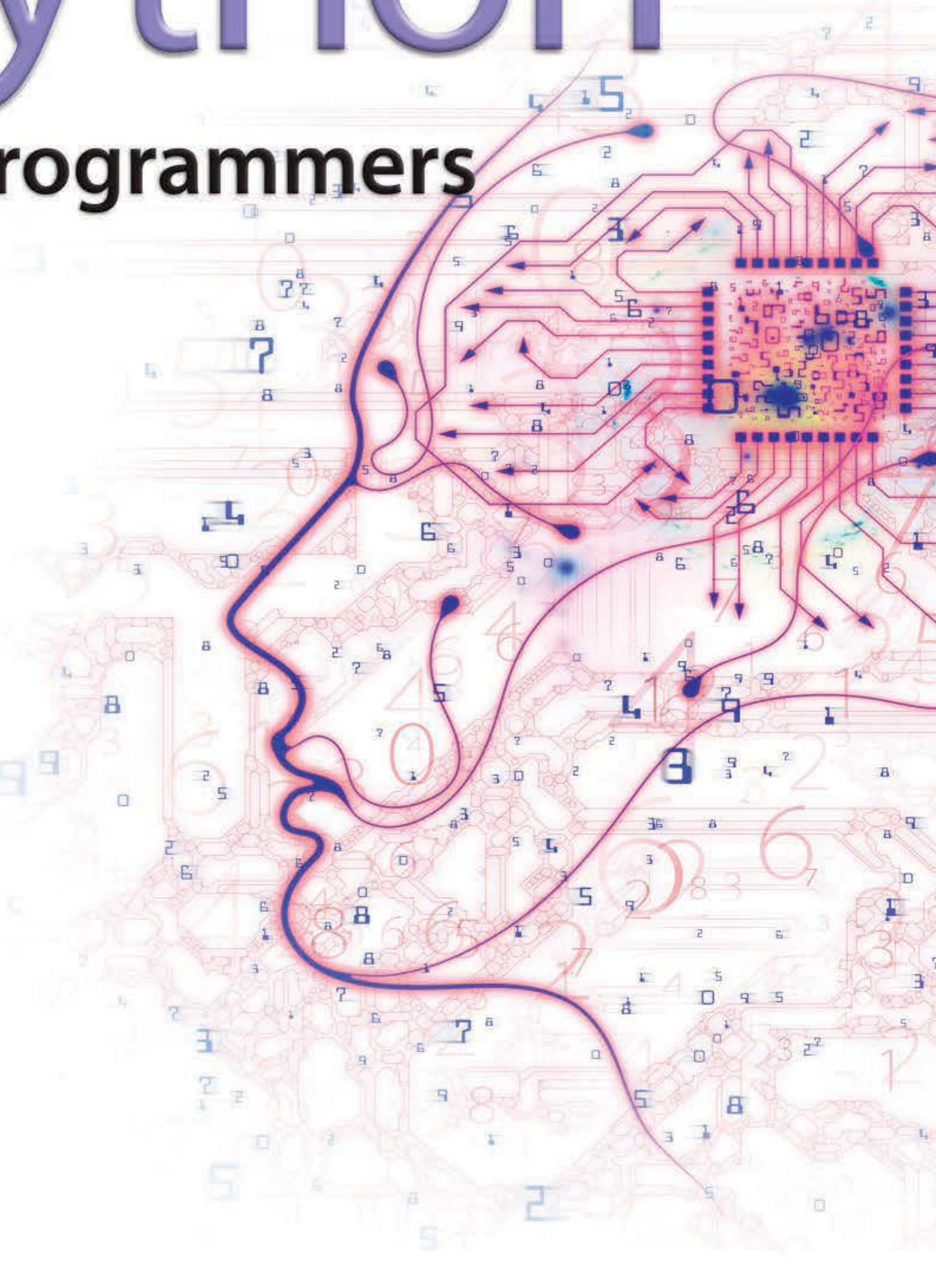

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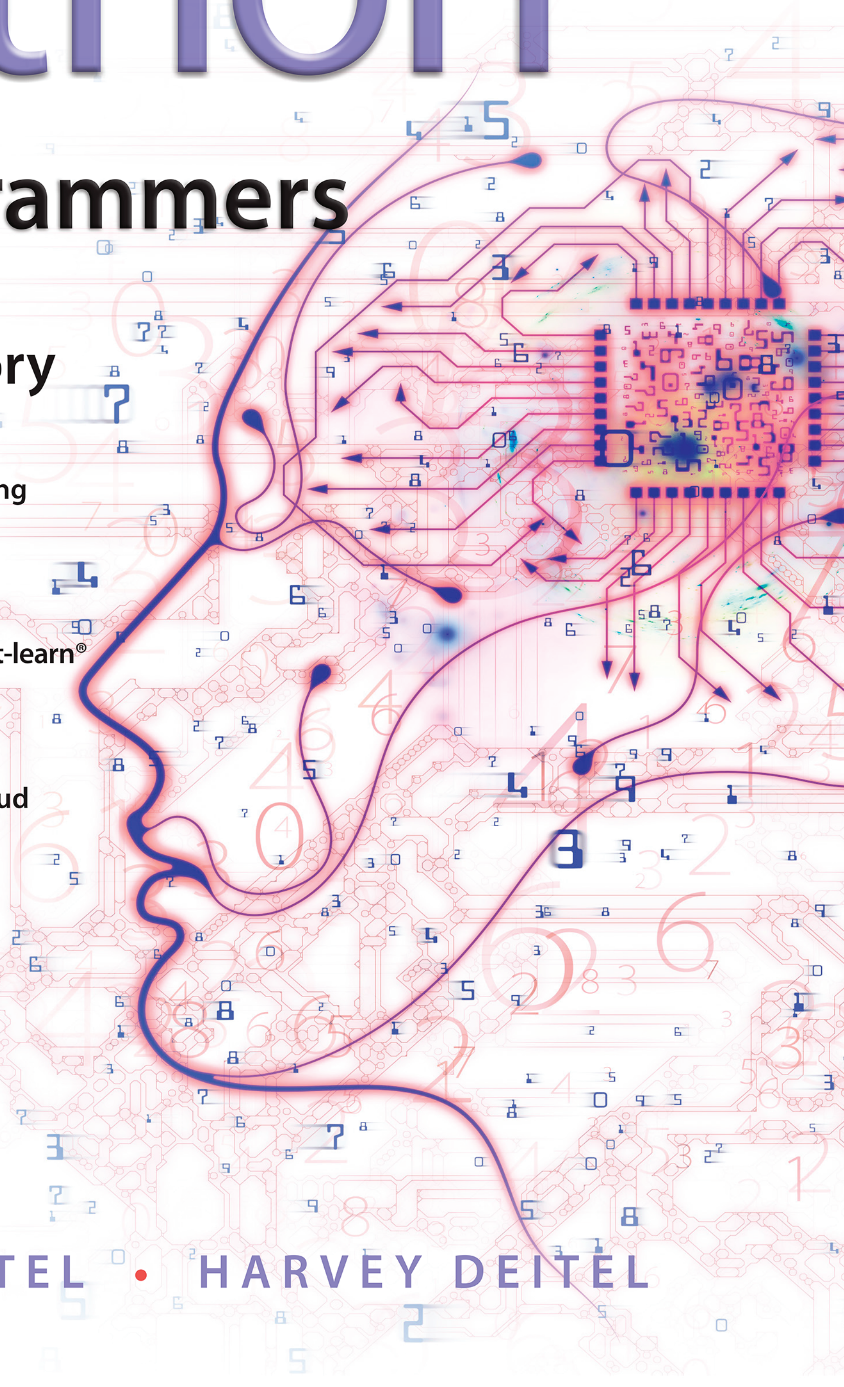

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1 19

In Memory of Marvin Minsky,
a founding father of
artificial intelligence

It was a privilege to be your student in two
artificial-intelligence graduate courses at M.I.T.
You inspired your students to think beyond limits.

Harvey Deitel

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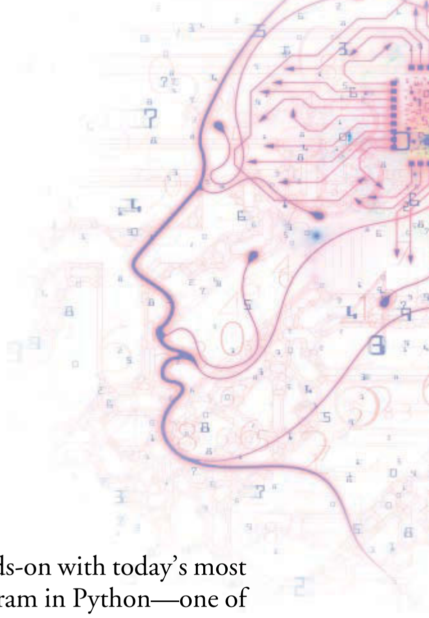

Preface

"There's gold in them thar hills!"[1]

Welcome to *Python for Programmers*! In this book, you'll learn hands-on with today's most compelling, leading-edge computing technologies, and you'll program in Python—one of the world's most popular languages and the fastest growing among them.

Developers often quickly discover that they like Python. They appreciate its expressive power, readability, conciseness and interactivity. They like the world of open-source software development that's generating a rapidly growing base of reusable software for an enormous range of application areas.

For many decades, some powerful trends have been in place. Computer hardware has rapidly been getting faster, cheaper and smaller. Internet bandwidth has rapidly been getting larger and cheaper. And quality computer software has become ever more abundant and essentially free or nearly free through the "open source" movement. Soon, the "Internet of Things" will connect tens of billions of devices of every imaginable type. These will generate enormous volumes of data at rapidly increasing speeds and quantities.

In computing today, the latest innovations are "all about the data"—*data* science, *data* analytics, big *data*, relational *data*bases (SQL), and NoSQL and NewSQL *data*bases, each of which we address along with an innovative treatment of Python programming.

Jobs Requiring Data Science Skills

In 2011, McKinsey Global Institute produced their report, "Big data: The next frontier for innovation, competition and productivity." In it, they said, "The United States alone faces a shortage of 140,000 to 190,000 people with deep analytical skills as well as 1.5 million managers and analysts to analyze big data and make decisions based on their findings."[2] This continues to be the case. The August 2018 "LinkedIn Workforce Report" says the United States has a shortage of over 150,000 people with data science skills.[3] A 2017 report from IBM, Burning Glass Technologies and the Business-Higher Education Forum, says that by 2020 in the United States there will be hundreds of thousands of new jobs requiring data science skills.[4]

[1] Source unknown, frequently misattributed to Mark Twain.

[2] `https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/Big%20data%20The%20next%20frontier%20for%20innovation/MGI_big_data_full_report.ashx` (page 3).

[3] `https://economicgraph.linkedin.com/resources/linkedin-workforce-report-august-2018`.

[4] `https://www.burning-glass.com/wp-content/uploads/The_Quant_Crunch.pdf` (page 3).

Modular Architecture

The book's **modular architecture** (please see the **Table of Contents graphic** on the book's inside front cover) helps us meet the diverse needs of various professional audiences.

Chapters 1–10 cover Python programming. These chapters each include a brief **Intro to Data Science** section introducing artificial intelligence, basic descriptive statistics, measures of central tendency and dispersion, simulation, static and dynamic visualization, working with CSV files, pandas for data exploration and data wrangling, time series and simple linear regression. These help you prepare for the data science, AI, big data and cloud case studies in Chapters 11–16, which present opportunities for you to use **real-world datasets** in complete case studies.

After covering Python Chapters 1–5 and a few key parts of Chapters 6–7, you'll be able to handle significant portions of the case studies in Chapters 11–16. The "Chapter Dependencies" section of this Preface will help trainers plan their professional courses in the context of the book's unique architecture.

Chapters 11–16 are loaded with cool, powerful, contemporary examples. They present hands-on implementation case studies on topics such as **natural language processing**, **data mining Twitter**, **cognitive computing with IBM's Watson**, **supervised machine learning with classification and regression**, **unsupervised machine learning with clustering**, **deep learning with convolutional neural networks**, **deep learning with recurrent neural networks**, **big data with Hadoop, Spark and NoSQL databases**, the **Internet of Things** and more. Along the way, you'll acquire a **broad literacy** of data science terms and concepts, ranging from brief definitions to using concepts in small, medium and large programs. Browsing the book's detailed **Table of Contents** and Index will give you a sense of the breadth of coverage.

Key Features

KIS (Keep It Simple), KIS (Keep it Small), KIT (Keep it Topical)

- **Keep it simple—**In every aspect of the book, we strive for **simplicity and clarity**. For example, when we present natural language processing, we use the simple and intuitive **TextBlob** library rather than the more complex NLTK. In our deep learning presentation, we prefer **Keras** to TensorFlow. In general, when multiple libraries could be used to perform similar tasks, we use the simplest one.
- **Keep it small—**Most of the book's 538 examples are small—often just a few lines of code, with immediate interactive **IPython** feedback. We also include 40 larger scripts and in-depth case studies.
- **Keep it topical—**We read scores of recent Python-programming and data science books, and browsed, read or watched about 15,000 current articles, research papers, white papers, videos, blog posts, forum posts and documentation pieces. This enabled us to "take the pulse" of the Python, computer science, data science, AI, big data and cloud communities.

Immediate-Feedback: Exploring, Discovering and Experimenting with IPython

- The ideal way to learn from this book is to read it and run the code examples in parallel. Throughout the book, we use the **IPython interpreter**, which provides a friendly, immediate-feedback interactive mode for quickly exploring, discovering and experimenting with Python and its extensive libraries.

- Most of the code is presented in **small, interactive IPython sessions**. For each code snippet you write, IPython immediately reads it, evaluates it and prints the results. This **instant feedback** keeps your attention, boosts learning, facilitates rapid prototyping and speeds the software-development process.
- Our books always emphasize the **live-code approach**, focusing on complete, working programs with live inputs and outputs. IPython's "magic" is that it turns even snippets into code that "comes alive" as you enter each line. This promotes learning and encourages experimentation.

Python Programming Fundamentals

- First and foremost, this book provides rich Python coverage.
- We discuss Python's programming models—**procedural programming**, **functional-style programming** and **object-oriented programming**.
- We use best practices, emphasizing current idiom.
- **Functional-style programming** is used throughout the book as appropriate. A chart in Chapter 4 lists most of Python's key functional-style programming capabilities and the chapters in which we initially cover most of them.

538 Code Examples

- You'll get an engaging, challenging and entertaining introduction to Python with **538 real-world examples** ranging from individual snippets to substantial computer science, data science, artificial intelligence and big data case studies.
- You'll attack significant tasks with **AI, big data and cloud** technologies like **natural language processing**, **data mining Twitter**, **machine learning**, **deep learning**, **Hadoop**, **MapReduce**, **Spark**, **IBM Watson**, key data science libraries (**NumPy**, **pandas**, **SciPy**, **NLTK**, **TextBlob**, **spaCy**, **Textatistic**, **Tweepy**, **Scikit-learn**, **Keras**), key visualization libraries (**Matplotlib**, **Seaborn**, **Folium**) and more.

Avoid Heavy Math in Favor of English Explanations

- We capture the conceptual essence of the mathematics and put it to work in our examples. We do this by using libraries such as **statistics**, **NumPy**, **SciPy**, **pandas** and many others, which hide the mathematical complexity. So, it's straightforward for you to get many of the benefits of mathematical techniques like **linear regression** without having to know the mathematics behind them. In the **machine-learning** and **deep-learning** examples, we focus on creating objects that do the math for you "behind the scenes."

Visualizations

- 67 **static, dynamic, animated and interactive visualizations** (charts, graphs, pictures, animations etc.) help you understand concepts.

- Rather than including a treatment of low-level graphics programming, we focus on high-level visualizations produced by **Matplotlib**, **Seaborn**, **pandas** and **Folium** (for **interactive maps**).
- We use visualizations as a pedagogic tool. For example, we make the **law of large numbers** "come alive" in a dynamic **die-rolling simulation** and bar chart. As the number of rolls increases, you'll see each face's percentage of the total rolls gradually approach 16.667% (1/6th) and the sizes of the bars representing the percentages equalize.
- Visualizations are crucial in big data for **data exploration** and **communicating reproducible research results**, where the data items can number in the millions, billions or more. A common saying is that a picture is worth a thousand words[5]—in **big data**, a visualization could be worth billions, trillions or even more items in a database. Visualizations enable you to "fly 40,000 feet above the data" to see it "in the large" and to get to know your data. **Descriptive statistics** help but can be misleading. For example, Anscombe's quartet[6] demonstrates through visualizations that *significantly different* datasets can have *nearly identical* descriptive statistics.
- We show the visualization and animation code so you can implement your own. We also provide the animations in source-code files and as **Jupyter Notebooks**, so you can conveniently customize the code and animation parameters, re-execute the animations and see the effects of the changes.

Data Experiences

- Our **Intro to Data Science sections** and case studies in Chapters 11–16 provide rich data experiences.
- You'll work with many **real-world datasets and data sources**. There's an enormous variety of **free open datasets** available online for you to experiment with. Some of the sites we reference list hundreds or thousands of datasets.
- Many libraries you'll use come bundled with popular datasets for experimentation.
- You'll learn the steps required to obtain data and prepare it for analysis, analyze that data using many techniques, tune your models and communicate your results effectively, especially through visualization.

GitHub

- **GitHub** is an excellent venue for finding open-source code to incorporate into your projects (and to contribute your code to the open-source community). It's also a crucial element of the software developer's arsenal with version control tools that help teams of developers manage open-source (and private) projects.
- You'll use an extraordinary range of free and open-source Python and data science **libraries**, and **free**, **free-trial** and **freemium** offerings of software and cloud services. Many of the libraries are hosted on GitHub.

[5] https://en.wikipedia.org/wiki/A_picture_is_worth_a_thousand_words.

[6] https://en.wikipedia.org/wiki/Anscombe%27s_quartet.

Hands-On Cloud Computing

- Much of big data analytics occurs in the cloud, where it's easy to scale *dynamically* the amount of hardware and software your applications need. You'll work with various cloud-based services (some directly and some indirectly), including **Twitter**, **Google Translate**, **IBM Watson**, **Microsoft Azure**, **OpenMapQuest**, **geopy**, **Dweet.io** and **PubNub**.
- We encourage you to use free, free trial or freemium cloud services. We prefer those that don't require a credit card because you don't want to risk accidentally running up big bills. **If you decide to use a service that requires a credit card, ensure that the tier you're using for free will not automatically jump to a paid tier.**

Database, Big Data and Big Data Infrastructure

- According to IBM (Nov. 2016), 90% of the world's data was created in the last two years.[7] Evidence indicates that the speed of data creation is rapidly accelerating.
- According to a March 2016 *AnalyticsWeek* article, within five years there will be over 50 billion devices connected to the Internet and by 2020 we'll be producing 1.7 megabytes of new data every second *for every person on the planet*![8]
- We include a treatment of **relational databases** and **SQL** with **SQLite**.
- Databases are critical **big data infrastructure** for storing and manipulating the massive amounts of data you'll process. Relational databases process *structured data*—they're not geared to the *unstructured* and *semi-structured data* in big data applications. So, as big data evolved, **NoSQL and NewSQL databases** were created to handle such data efficiently. We include a NoSQL and NewSQL overview and a hands-on case study with a **MongoDB JSON document database**. MongoDB is the most popular NoSQL database.
- We discuss **big data hardware and software infrastructure** in Chapter 16, "Big Data: Hadoop, Spark, NoSQL and IoT (Internet of Things)."

Artificial Intelligence Case Studies

- In case study Chapters 11–15, we present **artificial intelligence** topics, including **natural language processing**, **data mining Twitter to perform sentiment analysis**, **cognitive computing with IBM Watson**, **supervised machine learning**, **unsupervised machine learning** and **deep learning**. Chapter 16 presents the big data hardware and software infrastructure that enables computer scientists and data scientists to implement leading-edge AI-based solutions.

Built-In Collections: Lists, Tuples, Sets, Dictionaries

- There's little reason today for most application developers to build *custom* data structures. The book features a rich **two-chapter treatment of Python's built-in data structures—lists**, **tuples**, **dictionaries** and **sets**—with which most data-structuring tasks can be accomplished.

[7] `https://public.dhe.ibm.com/common/ssi/ecm/wr/en/wrl12345usen/watson-customer-engagement-watson-marketing-wr-other-papers-and-reports-wrl12345usen-20170719.pdf`.

[8] `https://analyticsweek.com/content/big-data-facts/`.

Array-Oriented Programming with NumPy Arrays and Pandas Series/DataFrames

- We also focus on three key data structures from open-source libraries—**NumPy arrays**, **pandas `Series`** and **pandas `DataFrames`**. These are used extensively in data science, computer science, artificial intelligence and big data. NumPy offers as much as two orders of magnitude higher performance than built-in Python lists.
- We include in Chapter 7 a rich treatment of NumPy arrays. Many libraries, such as pandas, are built on NumPy. The **Intro to Data Science sections** in Chapters 7–9 introduce pandas `Series` and `DataFrames`, which along with NumPy arrays are then used throughout the remaining chapters.

File Processing and Serialization

- Chapter 9 presents **text-file processing**, then demonstrates how to serialize objects using the popular **JSON (JavaScript Object Notation)** format. JSON is used frequently in the data science chapters.
- Many data science libraries provide built-in file-processing capabilities for loading datasets into your Python programs. In addition to plain text files, we process files in the popular **CSV (comma-separated values) format** using the Python Standard Library's `csv` module and capabilities of the pandas data science library.

Object-Based Programming

- We emphasize using the huge number of valuable classes that the **Python open-source community** has packaged into industry standard class libraries. You'll focus on knowing what libraries are out there, choosing the ones you'll need for your apps, creating objects from existing classes (usually in one or two lines of code) and making them "jump, dance and sing." This **object-*based* programming** enables you to build impressive applications quickly and concisely, which is a significant part of Python's appeal.
- With this approach, you'll be able to use machine learning, deep learning and other AI technologies to quickly solve a wide range of intriguing problems, including **cognitive computing** challenges like **speech recognition** and **computer vision**.

Object-Oriented Programming

- Developing *custom* classes is a crucial **object-oriented programming** skill, along with inheritance, polymorphism and duck typing. We discuss these in Chapter 10.
- Chapter 10 includes a discussion of **unit testing with `doctest`** and a fun card-shuffling-and-dealing simulation.
- Chapters 11–16 require only a few straightforward custom class definitions. In Python, you'll probably use more of an object-based programming approach than full-out object-oriented programming.

Reproducibility

- In the sciences in general, and data science in particular, there's a need to reproduce the results of experiments and studies, and to communicate those results effectively. **Jupyter Notebooks** are a preferred means for doing this.

- We discuss reproducibility throughout the book in the context of programming techniques and software such as Jupyter Notebooks and **Docker**.

Performance

- We use the **`%timeit` profiling tool** in several examples to compare the performance of different approaches to performing the same tasks. Other performance-related discussions include generator expressions, NumPy arrays vs. Python lists, performance of machine-learning and deep-learning models, and Hadoop and Spark distributed-computing performance.

Big Data and Parallelism

- In this book, rather than writing your own parallelization code, you'll let libraries like Keras running over TensorFlow, and big data tools like Hadoop and Spark parallelize operations for you. In this big data/AI era, the sheer processing requirements of massive data applications demand taking advantage of true parallelism provided by **multicore processors**, **graphics processing units** (GPUs), **tensor processing units** (TPUs) and huge ***clusters* of computers in the cloud**. Some big data tasks could have thousands of processors working in parallel to analyze massive amounts of data expeditiously.

Chapter Dependencies

If you're a trainer planning your syllabus for a professional training course or a developer deciding which chapters to read, this section will help you make the best decisions. Please read the one-page color **Table of Contents** on the book's inside front cover—this will quickly familiarize you with the book's unique architecture. Teaching or reading the chapters in order is easiest. However, much of the content in the Intro to Data Science sections at the ends of Chapters 1–10 and the case studies in Chapters 11–16 requires only Chapters 1–5 and small portions of Chapters 6–10 as discussed below.

Part 1: Python Fundamentals Quickstart

We recommend that you read all the chapters in order:

- **Chapter 1, Introduction to Computers and Python**, introduces concepts that lay the groundwork for the Python programming in Chapters 2–10 and the big data, artificial-intelligence and cloud-based case studies in Chapters 11–16. The chapter also includes **test-drives** of the **IPython** interpreter and **Jupyter Notebooks**.
- **Chapter 2, Introduction to Python Programming**, presents Python programming fundamentals with code examples illustrating key language features.
- **Chapter 3, Control Statements**, presents Python's **control statements** and introduces **basic list processing**.
- **Chapter 4, Functions**, introduces custom functions, presents **simulation techniques** with **random-number generation** and introduces **tuple fundamentals**.
- **Chapter 5, Sequences: Lists and Tuples**, presents Python's built-in list and tuple collections in more detail and begins introducing **functional-style programming**.

Part 2: Python Data Structures, Strings and Files

The following summarizes inter-chapter dependencies for Python Chapters 6–9 and assumes that you've read Chapters 1–5.

- **Chapter 6, Dictionaries and Sets**—The Intro to Data Science section in this chapter is not dependent on the chapter's contents.
- **Chapter 7, Array-Oriented Programming with NumPy**—The Intro to Data Science section requires dictionaries (Chapter 6) and arrays (Chapter 7).
- **Chapter 8, Strings: A Deeper Look**—The Intro to Data Science section requires raw strings and regular expressions (Sections 8.11–8.12), and pandas `Series` and `DataFrame` features from Section 7.14's Intro to Data Science.
- **Chapter 9, Files and Exceptions**—For **JSON serialization**, it's useful to understand dictionary fundamentals (Section 6.2). Also, the Intro to Data Science section requires the built-in `open` function and the `with` statement (Section 9.3), and pandas `DataFrame` features from Section 7.14's Intro to Data Science.

Part 3: Python High-End Topics

The following summarizes inter-chapter dependencies for Python Chapter 10 and assumes that you've read Chapters 1–5.

- **Chapter 10, Object-Oriented Programming**—The Intro to Data Science section requires pandas `DataFrame` features from Intro to Data Science Section 7.14. Trainers wanting to cover only **classes and objects** can present Sections 10.1–10.6. Trainers wanting to cover more advanced topics like **inheritance, polymorphism and duck typing**, can present Sections 10.7–10.9. Sections 10.10–10.15 provide additional advanced perspectives.

Part 4: AI, Cloud and Big Data Case Studies

The following summary of inter-chapter dependencies for Chapters 11–16 assumes that you've read Chapters 1–5. Most of Chapters 11–16 also require dictionary fundamentals from Section 6.2.

- **Chapter 11, Natural Language Processing** (**NLP**), uses pandas `DataFrame` features from Section 7.14's Intro to Data Science.
- **Chapter 12, Data Mining Twitter**, uses pandas `DataFrame` features from Section 7.14's Intro to Data Science, string method `join` (Section 8.9), JSON fundamentals (Section 9.5), `TextBlob` (Section 11.2) and Word clouds (Section 11.3). Several examples require defining a class via inheritance (Chapter 10).
- **Chapter 13, IBM Watson and Cognitive Computing**, uses built-in function `open` and the `with` statement (Section 9.3).
- **Chapter 14, Machine Learning: Classification, Regression and Clustering**, uses NumPy array fundamentals and method `unique` (Chapter 7), pandas `DataFrame` features from Section 7.14's Intro to Data Science and Matplotlib function `subplots` (Section 10.6).
- **Chapter 15, Deep Learning**, requires NumPy array fundamentals (Chapter 7), string method `join` (Section 8.9), general machine-learning concepts from

Chapter 14 and features from Chapter 14's Case Study: Classification with k-Nearest Neighbors and the Digits Dataset.

- **Chapter 16, Big Data: Hadoop, Spark, NoSQL and IoT**, uses string method `split` (Section 6.2.7), Matplotlib `FuncAnimation` from Section 6.4's Intro to Data Science, pandas `Series` and `DataFrame` features from Section 7.14's Intro to Data Science, string method `join` (Section 8.9), the `json` module (Section 9.5), NLTK stop words (Section 11.2.13) and from Chapter 12, Twitter authentication, Tweepy's `StreamListener` class for streaming tweets, and the `geopy` and `folium` libraries. A few examples require defining a class via inheritance (Chapter 10), but you can simply mimic the class definitions we provide without reading Chapter 10.

Jupyter Notebooks

For your convenience, we provide the book's code examples in **Python source code (`.py`) files** for use with the command-line IPython interpreter *and* as **Jupyter Notebooks (`.ipynb`) files** that you can load into your web browser and execute.

Jupyter Notebooks is a free, open-source project that enables you to combine text, graphics, audio, video, and interactive coding functionality for entering, editing, executing, debugging, and modifying code quickly and conveniently in a web browser. According to the article, "What Is Jupyter?":

> *Jupyter has become a standard for scientific research and data analysis. It packages computation and argument together, letting you build "computational narratives"; … and it simplifies the problem of distributing working software to teammates and associates.*[9]

In our experience, it's a wonderful learning environment and **rapid prototyping tool**. For this reason, we use **Jupyter Notebooks** rather than a traditional IDE, such as **Eclipse**, **Visual Studio**, **PyCharm** or **Spyder**. Academics and professionals already use Jupyter extensively for sharing research results. Jupyter Notebooks support is provided through the traditional open-source community mechanisms[10] (see "Getting Jupyter Help" later in this Preface). See the Before You Begin section that follows this Preface for software installation details and see the test-drives in Section 1.5 for information on running the book's examples.

Collaboration and Sharing Results

Working in teams and communicating research results are both important for developers in or moving into data-analytics positions in industry, government or academia:

- The notebooks you create are **easy to share** among team members simply by copying the files or via **GitHub**.
- Research results, including code and insights, can be shared as static web pages via tools like **nbviewer** (`https://nbviewer.jupyter.org`) and **GitHub**—both automatically render notebooks as web pages.

[9] `https://www.oreilly.com/ideas/what-is-jupyter`.

[10] `https://jupyter.org/community`.

Reproducibility: A Strong Case for Jupyter Notebooks

In data science, and in the sciences in general, experiments and studies should be reproducible. This has been written about in the literature for many years, including

- Donald Knuth's 1992 computer science publication—*Literate Programming.*[11]
- The article "Language-Agnostic Reproducible Data Analysis Using Literate Programming,"[12] which says, "Lir (literate, reproducible computing) is based on the idea of literate programming as proposed by Donald Knuth."

Essentially, reproducibility captures the complete environment used to produce results—hardware, software, communications, algorithms (especially code), data and the **data's provenance** (origin and lineage).

Docker

In Chapter 16, we'll use **Docker**—a tool for packaging software into containers that bundle everything required to execute that software conveniently, reproducibly and portably across platforms. Some software packages we use in Chapter 16 require complicated setup and configuration. For many of these, you can download free preexisting **Docker containers**. These enable you to avoid complex installation issues and execute software locally on your desktop or notebook computers, making Docker a great way to help you get started with new technologies quickly and conveniently.

Docker also helps with reproducibility. You can create custom Docker containers that are configured with the versions of every piece of software and every library you used in your study. This would enable other developers to recreate the environment you used, then reproduce your work, and will help you reproduce your own results. In Chapter 16, you'll use Docker to download and execute a container that's preconfigured for you to code and run big data Spark applications using Jupyter Notebooks.

Special Feature: IBM Watson Analytics and Cognitive Computing

Early in our research for this book, we recognized the rapidly growing interest in **IBM's Watson**. We investigated competitive services and found Watson's "no credit card required" policy for its "free tiers" to be among the most friendly for our readers.

IBM Watson is a **cognitive-computing** platform being employed across a wide range of real-world scenarios. Cognitive-computing systems simulate the **pattern-recognition** and **decision-making** capabilities of the human brain to "learn" as they consume more data.[13,14,15] We include a significant hands-on Watson treatment. We use the free **Watson Developer Cloud: Python SDK**, which provides APIs that enable you to interact with Watson's services programmatically. Watson is fun to use and a great platform for letting your creative juices flow. You'll demo or use the following Watson APIs: **Conversation**, **Discovery**, **Language Translator**, **Natural Language Classifier**, **Natural Language**

[11] Knuth, D., "Literate Programming" (PDF), *The Computer Journal*, British Computer Society, 1992.

[12] `http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0164023`.

[13] `http://whatis.techtarget.com/definition/cognitive-computing`.

[14] `https://en.wikipedia.org/wiki/Cognitive_computing`.

[15] `https://www.forbes.com/sites/bernardmarr/2016/03/23/what-everyone-should-know-about-cognitive-computing`.

Understanding, **Personality Insights**, **Speech to Text**, **Text to Speech**, **Tone Analyzer** and **Visual Recognition**.

Watson's Lite Tier Services and a Cool Watson Case Study

IBM encourages learning and experimentation by providing *free lite tiers* for many of its APIs.[16] In Chapter 13, you'll try demos of many Watson services.[17] Then, you'll use the lite tiers of Watson's **Text to Speech**, **Speech to Text** and **Translate** services to implement a "**traveler's assistant**" **translation app**. You'll speak a question in English, then the app will transcribe your speech to English text, translate the text to Spanish and speak the Spanish text. Next, you'll speak a Spanish response (in case you don't speak Spanish, we provide an audio file you can use). Then, the app will quickly transcribe the speech to Spanish text, translate the text to English and speak the English response. Cool stuff!

Teaching Approach

Python for Programmers contains a rich collection of examples drawn from many fields. You'll work through interesting, real-world examples using **real-world datasets**. The book concentrates on the principles of good **software engineering** and stresses **program clarity**.

Using Fonts for Emphasis

We place the key terms and the index's page reference for each defining occurrence in **bold** text for easier reference. We refer to on-screen components in the **bold Helvetica** font (for example, the **File** menu) and use the `Lucida` font for Python code (for example, `x = 5`).

Syntax Coloring

For readability, we syntax color all the code. Our syntax-coloring conventions are as follows:

```
comments appear in green
keywords appear in dark blue
constants and literal values appear in light blue
errors appear in red
all other code appears in black
```

538 Code Examples

The book's **538 examples** contain approximately **4000 lines of code**. This is a relatively small amount for a book this size and is due to the fact that Python is such an expressive language. Also, our coding style is to use powerful class libraries to do most of the work wherever possible.

160 Tables/Illustrations/Visualizations

We include abundant tables, line drawings, and static, dynamic and interactive visualizations.

[16] Always check the latest terms on IBM's website, as the terms and services may change.

[17] `https://console.bluemix.net/catalog/`.

Programming Wisdom

We *integrate* into the discussions programming wisdom from the authors' combined nine decades of programming and teaching experience, including:

- **Good programming practices** and preferred Python idioms that help you produce clearer, more understandable and more maintainable programs.
- **Common programming errors** to reduce the likelihood that you'll make them.
- **Error-prevention tips** with suggestions for exposing bugs and removing them from your programs. Many of these tips describe techniques for preventing bugs from getting into your programs in the first place.
- **Performance tips** that highlight opportunities to make your programs run faster or minimize the amount of memory they occupy.
- **Software engineering observations** that highlight architectural and design issues for proper software construction, especially for larger systems.

Software Used in the Book

The software we use is available for Windows, macOS and Linux and is free for download from the Internet. We wrote the book's examples using the free **Anaconda Python distribution**. It includes most of the Python, visualization and data science libraries you'll need, as well as the IPython interpreter, Jupyter Notebooks and Spyder, considered one of the best Python data science IDEs. We use only IPython and Jupyter Notebooks for program development in the book. The Before You Begin section following this Preface discusses installing Anaconda and a few other items you'll need for working with our examples.

Python Documentation

You'll find the following documentation especially helpful as you work through the book:

- The Python Language Reference:

  `https://docs.python.org/3/reference/index.html`
- The Python Standard Library:

  `https://docs.python.org/3/library/index.html`
- Python documentation list:

  `https://docs.python.org/3/`

Getting Your Questions Answered

Popular Python and general programming online forums include:

- `python-forum.io`
- `https://www.dreamincode.net/forums/forum/29-python/`
- `StackOverflow.com`

Also, many vendors provide forums for their tools and libraries. Many of the libraries you'll use in this book are managed and maintained at `github.com`. Some library maintainers provide support through the **Issues** tab on a given library's GitHub page. If you cannot find an answer to your questions online, please see our web page for the book at

`http://www.deitel.com`[18]

Getting Jupyter Help

Jupyter Notebooks support is provided through:

- Project Jupyter Google Group:
  `https://groups.google.com/forum/#!forum/jupyter`
- Jupyter real-time chat room:
  `https://gitter.im/jupyter/jupyter`
- GitHub
  `https://github.com/jupyter/help`
- StackOverflow:
  `https://stackoverflow.com/questions/tagged/jupyter`
- Jupyter for Education Google Group (for instructors teaching with Jupyter):
  `https://groups.google.com/forum/#!forum/jupyter-education`

Supplements

To get the most out of the presentation, you should execute each code example in parallel with reading the corresponding discussion in the book. On the book's web page at

`http://www.deitel.com`

we provide:

- **Downloadable Python source code** (`.py` files) and **Jupyter Notebooks** (`.ipynb` files) for the book's **code examples**.
- **Getting Started videos** showing how to use the code examples with IPython and Jupyter Notebooks. We also introduce these tools in Section 1.5.
- **Blog posts** and **book updates**.

For download instructions, see the Before You Begin section that follows this Preface.

Keeping in Touch with the Authors

For answers to questions or to report an error, send an e-mail to us at

`deitel@deitel.com`

or interact with us via **social media**:

- **Facebook**® (`http://www.deitel.com/deitelfan`)
- **Twitter**® (`@deitel`)
- **LinkedIn**® (`http://linkedin.com/company/deitel-&-associates`)
- **YouTube**® (`http://youtube.com/DeitelTV`)

[18] Our website is undergoing a major upgrade. If you do not find something you need, please write to us directly at `deitel@deitel.com`.

Acknowledgments

We'd like to thank Barbara Deitel for long hours devoted to Internet research on this project. We're fortunate to have worked with the dedicated team of publishing professionals at Pearson. We appreciate the efforts and 25-year mentorship of our friend and colleague Mark L. Taub, Vice President of the Pearson IT Professional Group. Mark and his team publish our professional books, LiveLessons video products and Learning Paths in the Safari service (`https://learning.oreilly.com/`). They also sponsor our Safari live online training seminars. Julie Nahil managed the book's production. We selected the cover art and Chuti Prasertsith designed the cover.

We wish to acknowledge the efforts of our reviewers. Patricia Byron-Kimball and Meghan Jacoby recruited the reviewers and managed the review process. Adhering to a tight schedule, the reviewers scrutinized our work, providing countless suggestions for improving the accuracy, completeness and timeliness of the presentation.

Reviewers

Book Reviewers

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Jamie Whitacre, Independent Data Science Consultant

As you read the book, we'd appreciate your comments, criticisms, corrections and suggestions for improvement. Please send all correspondence to:

```
deitel@deitel.com
```

We'll respond promptly.

Welcome again to the exciting open-source world of Python programming. We hope you enjoy this look at leading-edge computer-applications development with Python, IPython, Jupyter Notebooks, data science, AI, big data and the cloud. We wish you great success!

Paul and Harvey Deitel

About the Authors

Paul J. Deitel, CEO and Chief Technical Officer of Deitel & Associates, Inc., is an MIT graduate with 38 years of experience in computing. Paul is one of the world's most experienced programming-languages trainers, having taught professional courses to software developers since 1992. He has delivered hundreds of programming courses to industry clients internationally, including Cisco, IBM, Siemens, Sun Microsystems (now Oracle), Dell, Fidelity, NASA at the Kennedy Space Center, the National Severe Storm Laboratory, White Sands Missile Range, Rogue Wave Software, Boeing, Nortel Networks, Puma, iRobot and many more. He and his co-author, Dr. Harvey M. Deitel, are the world's best-selling programming-language textbook/professional book/video authors.

Dr. Harvey M. Deitel, Chairman and Chief Strategy Officer of Deitel & Associates, Inc., has 58 years of experience in computing. Dr. Deitel earned B.S. and M.S. degrees in Electrical Engineering from MIT and a Ph.D. in Mathematics from Boston University—he studied computing in each of these programs before they spun off Computer Science programs. He has extensive college teaching experience, including earning tenure and serving as the Chairman of the Computer Science Department at Boston College before founding Deitel & Associates, Inc., in 1991 with his son, Paul. The Deitels' publications have earned international recognition, with more than 100 translations published in Japanese, German, Russian, Spanish, French, Polish, Italian, Simplified Chinese, Traditional Chinese, Korean, Portuguese, Greek, Urdu and Turkish. Dr. Deitel has delivered hundreds of programming courses to academic, corporate, government and military clients.

About Deitel® & Associates, Inc.

Deitel & Associates, Inc., founded by Paul Deitel and Harvey Deitel, is an internationally recognized authoring and corporate training organization, specializing in computer programming languages, object technology, mobile app development and Internet and web software technology. The company's training clients include some of the world's largest companies, government agencies, branches of the military and academic institutions. The company offers instructor-led training courses delivered at client sites worldwide on major programming languages.

Through its 44-year publishing partnership with Pearson/Prentice Hall, Deitel & Associates, Inc., publishes leading-edge programming textbooks and professional books in print and e-book formats, **LiveLessons** video courses (available for purchase at `https://www.informit.com`), **Learning Paths** and live online training seminars in the Safari service (`https://learning.oreilly.com`) and **Revel™** interactive multimedia courses.

To contact Deitel & Associates, Inc. and the authors, or to request a proposal on-site, instructor-led training, write to:

`deitel@deitel.com`

To learn more about Deitel on-site corporate training, visit

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http://www.deitel.com/training
```

Individuals wishing to purchase Deitel books can do so at

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https://www.amazon.com
```
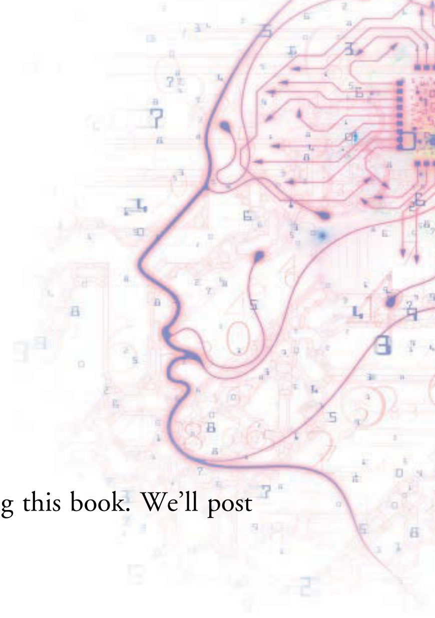

Bulk orders by corporations, the government, the military and academic institutions should be placed directly with Pearson. For more information, visit

```
https://www.informit.com/store/sales.aspx
```



Before You Begin

This section contains information you should review before using this book. We'll post updates at: `http://www.deitel.com`.

Font and Naming Conventions

We show Python code and commands and file and folder names in a `sans-serif font`, and on-screen components, such as menu names, in a **bold sans-serif font**. We use *italics for emphasis* and **bold occasionally for strong emphasis**.

Getting the Code Examples

You can download the `examples.zip` file containing the book's examples from our *Python for Programmers* web page at:

```
http://www.deitel.com
```

Click the **Download Examples** link to save the file to your local computer. Most web browsers place the file in your user account's `Downloads` folder. When the download completes, locate it on your system, and extract its `examples` folder into your user account's `Documents` folder:

- Windows: `C:\Users\`*YourAccount*`\Documents\examples`
- macOS or Linux: `~/Documents/examples`

Most operating systems have a built-in extraction tool. You also may use an archive tool such as 7-Zip (`www.7-zip.org`) or WinZip (`www.winzip.com`).

Structure of the `examples` Folder

You'll execute three kinds of examples in this book:

- Individual code snippets in the IPython interactive environment.
- Complete applications, which are known as scripts.
- Jupyter Notebooks—a convenient interactive, web-browser-based environment in which you can write and execute code and intermix the code with text, images and video.

We demonstrate each in Section 1.5's test drives.

The `examples` folder contains one subfolder per chapter. These are named `ch##`, where ## is the two-digit chapter number `01` to `16`—for example, `ch01`. Except for Chapters 13, 15 and 16, each chapter's folder contains the following items:

- `snippets_ipynb`—A folder containing the chapter's Jupyter Notebook files.

- snippets_py—A folder containing Python source code files in which each code snippet we present is separated from the next by a blank line. You can copy and paste these snippets into IPython or into new Jupyter Notebooks that you create.
- Script files and their supporting files.

Chapter 13 contains one application. Chapters 15 and 16 explain where to find the files you need in the ch15 and ch16 folders, respectively.

Installing Anaconda

We use the easy-to-install Anaconda Python distribution with this book. It comes with almost everything you'll need to work with our examples, including:

- the IPython interpreter,
- most of the Python and data science libraries we use,
- a local Jupyter Notebooks server so you can load and execute our notebooks, and
- various other software packages, such as the Spyder Integrated Development Environment (IDE)—we use only IPython and Jupyter Notebooks in this book.

Download the Python 3.x Anaconda installer for Windows, macOS or Linux from:

```
https://www.anaconda.com/download/
```

When the download completes, run the installer and follow the on-screen instructions. To ensure that Anaconda runs correctly, do not move its files after you install it.

Updating Anaconda

Next, ensure that Anaconda is up to date. Open a command-line window on your system as follows:

- On macOS, open a **Terminal** from the **Applications** folder's **Utilities** subfolder.
- On Windows, open the **Anaconda Prompt** from the start menu. When doing this to update Anaconda (as you'll do here) or to install new packages (discussed momentarily), execute the **Anaconda Prompt** as an *administrator* by right-clicking, then selecting **More > Run as administrator**. (If you cannot find the Anaconda Prompt in the start menu, simply search for it in the **Type here to search** field at the bottom of your screen.)
- On Linux, open your system's **Terminal** or shell (this varies by Linux distribution).

In your system's command-line window, execute the following commands to update Anaconda's installed packages to their latest versions:

1. `conda update conda`
2. `conda update --all`

Package Managers

The conda command used above invokes the **conda package manager**—one of the two key Python package managers you'll use in this book. The other is **pip**. Packages contain the files required to install a given Python library or tool. Throughout the book, you'll use conda to install additional packages, unless those packages are not available through conda, in which case you'll use pip. Some people prefer to use pip exclusively as it currently supports more packages. If you ever have trouble installing a package with conda, try pip instead.

Installing the Prospector Static Code Analysis Tool

You may want to analyze you Python code using the Prospector analysis tool, which checks your code for common errors and helps you improve it. To install Prospector and the Python libraries it uses, run the following command in the command-line window:

```
pip install prospector
```

Installing jupyter-matplotlib

We implement several animations using a visualization library called Matplotlib. To use them in Jupyter Notebooks, you must install a tool called ipympl. In the **Terminal**, **Anaconda Command Prompt** or shell you opened previously, execute the following commands[1] one at a time:

```
conda install -c conda-forge ipympl
conda install nodejs
jupyter labextension install @jupyter-widgets/jupyterlab-manager
jupyter labextension install jupyter-matplotlib
```

Installing the Other Packages

Anaconda comes with approximately 300 popular Python and data science packages for you, such as NumPy, Matplotlib, pandas, Regex, BeautifulSoup, requests, Bokeh, SciPy, SciKit-Learn, Seaborn, Spacy, sqlite, statsmodels and many more. The number of additional packages you'll need to install throughout the book will be small and we'll provide installation instructions as necessary. As you discover new packages, their documentation will explain how to install them.

Get a Twitter Developer Account

If you intend to use our "Data Mining Twitter" chapter and any Twitter-based examples in subsequent chapters, apply for a Twitter developer account. Twitter now requires registration for access to their APIs. To apply, fill out and submit the application at

```
https://developer.twitter.com/en/apply-for-access
```

Twitter reviews every application. At the time of this writing, personal developer accounts were being approved immediately and company-account applications were taking from several days to several weeks. Approval is not guaranteed.

Internet Connection Required in Some Chapters

While using this book, you'll need an Internet connection to install various additional Python libraries. In some chapters, you'll register for accounts with cloud-based services, mostly to use their free tiers. Some services require credit cards to verify your identity. In

[1] https://github.com/matplotlib/jupyter-matplotlib.

a few cases, you'll use services that are not free. In these cases, you'll take advantage of monetary credits provided by the vendors so you can try their services without incurring charges. **Caution: Some cloud-based services incur costs once you set them up. When you complete our case studies using such services, be sure to promptly delete the resources you allocated.**

Slight Differences in Program Outputs

When you execute our examples, you might notice some differences between the results we show and your own results:

- Due to differences in how calculations are performed with floating-point numbers (like –123.45, 7.5 or 0.0236937) across operating systems, you might see minor variations in outputs—especially in digits far to the right of the decimal point.
- When we show outputs that appear in separate windows, we crop the windows to remove their borders.

Getting Your Questions Answered

Online forums enable you to interact with other Python programmers and get your Python questions answered. Popular Python and general programming forums include:

- `python-forum.io`
- `StackOverflow.com`
- `https://www.dreamincode.net/forums/forum/29-python/`

Also, many vendors provide forums for their tools and libraries. Most of the libraries you'll use in this book are managed and maintained at `github.com`. Some library maintainers provide support through the **Issues** tab on a given library's GitHub page. If you cannot find an answer to your questions online, please see our web page for the book at

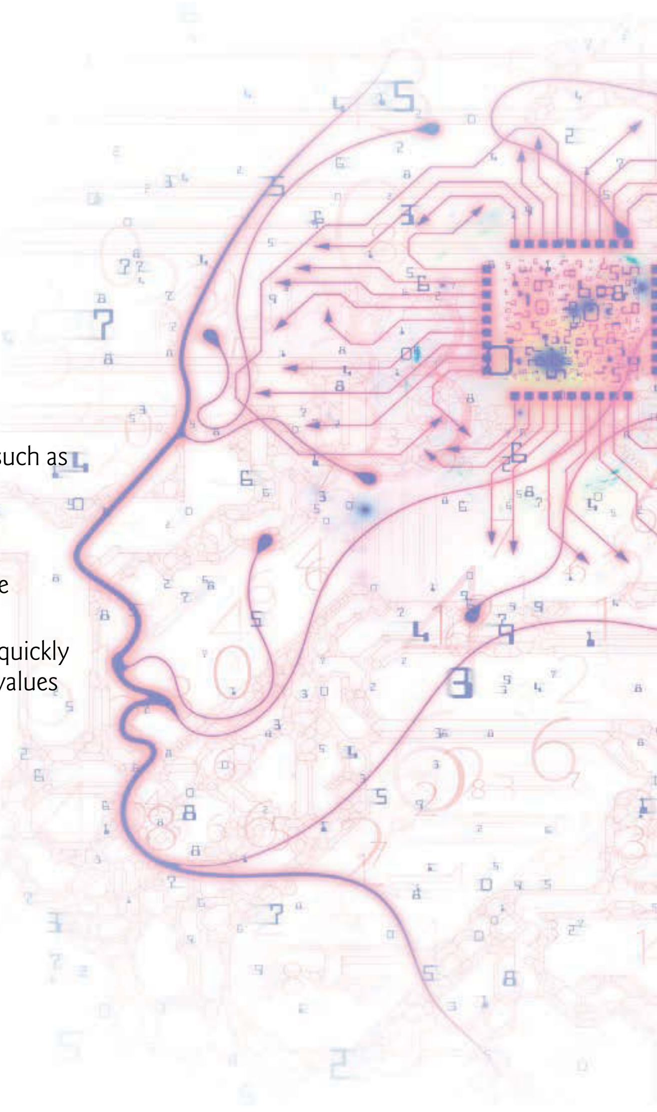
`http://www.deitel.com`[2]

You're now ready to begin reading *Python for Programmers*. We hope you enjoy the book!

[2] Our website is undergoing a major upgrade. If you do not find something you need, please write to us directly at `deitel@deitel.com`.

5

Sequences: Lists and Tuples



Objectives

In this chapter, you'll:

- Create and initialize lists and tuples.
- Refer to elements of lists, tuples and strings.
- Sort and search lists, and search tuples.
- Pass lists and tuples to functions and methods.
- Use list methods to perform common manipulations, such as searching for items, sorting a list, inserting items and removing items.
- Use additional Python functional-style programming capabilities, including lambdas and the functional-style programming operations filter, map and reduce.
- Use functional-style list comprehensions to create lists quickly and easily, and use generator expressions to generate values on demand.
- Use two-dimensional lists.
- Enhance your analysis and presentation skills with the Seaborn and Matplotlib visualization libraries.

Outline

5.1 Introduction
5.2 Lists
5.3 Tuples
5.4 Unpacking Sequences
5.5 Sequence Slicing
5.6 `del` Statement
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5.8 Sorting Lists
5.9 Searching Sequences
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5.12 List Comprehensions
5.13 Generator Expressions
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5.15 Other Sequence Processing Functions
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5.17 Intro to Data Science: Simulation and Static Visualizations
5.17.1 Sample Graphs for 600, 60,000 and 6,000,000 Die Rolls
5.17.2 Visualizing Die-Roll Frequencies and Percentages
5.18 Wrap-Up

5.1 Introduction

In the last two chapters, we briefly introduced the list and tuple sequence types for representing ordered collections of items. **Collections** are prepackaged data structures consisting of related data items. Examples of collections include your favorite songs on your smartphone, your contacts list, a library's books, your cards in a card game, your favorite sports team's players, the stocks in an investment portfolio, patients in a cancer study and a shopping list. Python's built-in collections enable you to store and access data conveniently and efficiently. In this chapter, we discuss lists and tuples in more detail.

We'll demonstrate common list and tuple manipulations. You'll see that lists (which are modifiable) and tuples (which are not) have many common capabilities. Each can hold items of the same or different types. Lists can **dynamically resize** as necessary, growing and shrinking at execution time. We discuss one-dimensional and two-dimensional lists.

In the preceding chapter, we demonstrated random-number generation and simulated rolling a six-sided die. We conclude this chapter with our next Intro to Data Science section, which uses the visualization libraries Seaborn and Matplotlib to interactively develop static bar charts containing the die frequencies. In the next chapter's Intro to Data Science section, we'll present an animated visualization in which the bar chart changes *dynamically* as the number of die rolls increases—you'll see the law of large numbers "in action."

5.2 Lists

Here, we discuss lists in more detail and explain how to refer to particular list **elements**. Many of the capabilities shown in this section apply to all sequence types.

Creating a List

Lists typically store **homogeneous data**, that is, values of the *same* data type. Consider the list `c`, which contains five integer elements:

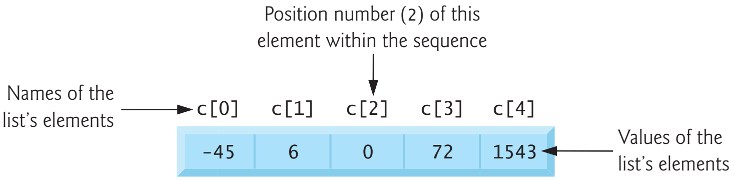
```
In [1]: c = [-45, 6, 0, 72, 1543]

In [2]: c
Out[2]: [-45, 6, 0, 72, 1543]
```

They also may store **heterogeneous data**, that is, data of many different types. For example, the following list contains a student's first name (a string), last name (a string), grade point average (a `float`) and graduation year (an `int`):

```
['Mary', 'Smith', 3.57, 2022]
```

Accessing Elements of a List

You reference a list element by writing the list's name followed by the element's **index** (that is, its **position number**) enclosed in square brackets (`[]`, known as the **subscription operator**). The following diagram shows the list `c` labeled with its element names:


Position number (2) of this element within the sequence
Names of the list's elements
c[0]
c[1]
c[2]
c[3]
c[4]
-45
6
0
72
1543
Values of the list's elements

The first element in a list has the index `0`. So, in the five-element list `c`, the first element is named `c[0]` and the last is `c[4]`:

```
In [3]: c[0]
Out[3]: -45

In [4]: c[4]
Out[4]: 1543
```

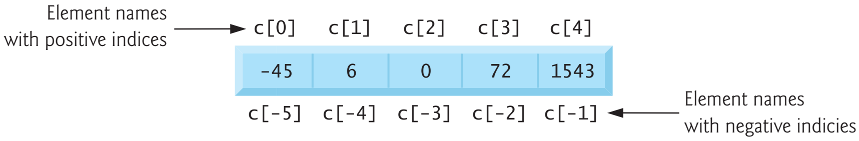
Determining a List's Length

To get a list's length, use the built-in **`len` function**:

```
In [5]: len(c)
Out[5]: 5
```

Accessing Elements from the End of the List with Negative Indices

Lists also can be accessed from the end by using *negative indices*:


Element names with positive indices
c[0]
c[1]
c[2]
c[3]
c[4]
-45
6
0
72
1543
c[-5]
c[-4]
c[-3]
c[-2]
c[-1]
Element names with negative indicies

So, list `c`'s last element (`c[4]`), can be accessed with `c[-1]` and its first element with `c[-5]`:

```
In [6]: c[-1]
Out[6]: 1543

In [7]: c[-5]
Out[7]: -45
```

Indices Must Be Integers or Integer Expressions

An index must be an integer or integer expression (or a *slice*, as we'll soon see):

```
In [8]: a = 1

In [9]: b = 2
In [10]: c[a + b]
Out[10]: 72
```

Using a non-integer index value causes a `TypeError`.

Lists Are Mutable

Lists are mutable—their elements can be modified:

```
In [11]: c[4] = 17

In [12]: c
Out[12]: [-45, 6, 0, 72, 17]
```

You'll soon see that you also can insert and delete elements, changing the list's length.

Some Sequences Are Immutable

Python's string and tuple sequences are immutable—they cannot be modified. You can get the individual characters in a string, but attempting to assign a new value to one of the characters causes a `TypeError`:

```
In [13]: s = 'hello'

In [14]: s[0]
Out[14]: 'h'

In [15]: s[0] = 'H'
---------------------------------------------------------------------------
TypeError                                 Traceback (most recent call last)
<ipython-input-15-812ef2514689> in <module>()
----> 1 s[0] = 'H'

TypeError: 'str' object does not support item assignment
```

Attempting to Access a Nonexistent Element

Using an out-of-range list, tuple or string index causes an `IndexError`:

```
In [16]: c[100]
---------------------------------------------------------------------------
IndexError                                Traceback (most recent call last)
<ipython-input-16-9a31ea1e1a13> in <module>()
----> 1 c[100]

IndexError: list index out of range
```

Using List Elements in Expressions

List elements may be used as variables in expressions:

```
In [17]: c[0] + c[1] + c[2]
Out[17]: -39
```

Appending to a List with +=

Let's start with an *empty* list `[]`, then use a `for` statement and `+=` to append the values 1 through 5 to the list—the list grows dynamically to accommodate each item:

```
In [18]: a_list = []
In [19]: for number in range(1, 6):
    ...:     a_list += [number]
    ...:

In [20]: a_list
Out[20]: [1, 2, 3, 4, 5]
```

When the left operand of += is a list, the right operand must be an *iterable*; otherwise, a TypeError occurs. In snippet [19]'s suite, the square brackets around number create a one-element list, which we append to a_list. If the right operand contains multiple elements, += appends them all. The following appends the characters of 'Python' to the list letters:

```
In [21]: letters = []

In [22]: letters += 'Python'

In [23]: letters
Out[23]: ['P', 'y', 't', 'h', 'o', 'n']
```

If the right operand of += is a tuple, its elements also are appended to the list. Later in the chapter, we'll use the list method append to add items to a list.

Concatenating Lists with +

You can **concatenate** two lists, two tuples or two strings using the + operator. The result is a *new* sequence of the same type containing the left operand's elements followed by the right operand's elements. The original sequences are unchanged:

```
In [24]: list1 = [10, 20, 30]

In [25]: list2 = [40, 50]

In [26]: concatenated_list = list1 + list2

In [27]: concatenated_list
Out[27]: [10, 20, 30, 40, 50]
```

A TypeError occurs if the + operator's operands are difference sequence types—for example, concatenating a list and a tuple is an error.

Using for and range to Access List Indices and Values

List elements also can be accessed via their indices and the subscription operator ([]):

```
In [28]: for i in range(len(concatenated_list)):
    ...:     print(f'{i}: {concatenated_list[i]}')
    ...:
0: 10
1: 20
2: 30
3: 40
4: 50
```

The function call range(len(concatenated_list)) produces a sequence of integers representing concatenated_list's indices (in this case, 0 through 4). When looping in this manner, you must ensure that indices remain in range. Soon, we'll show a safer way to access element indices and values using built-in function enumerate.

Comparison Operators

You can compare entire lists element-by-element using comparison operators:

```
In [29]: a = [1, 2, 3]

In [30]: b = [1, 2, 3]

In [31]: c = [1, 2, 3, 4]

In [32]: a == b  # True: corresponding elements in both are equal
Out[32]: True

In [33]: a == c  # False: a and c have different elements and lengths
Out[33]: False

In [34]: a < c  # True: a has fewer elements than c
Out[34]: True

In [35]: c >= b  # True: elements 0-2 are equal but c has more elements
Out[35]: True
```

5.3 Tuples

As discussed in the preceding chapter, tuples are immutable and typically store heterogeneous data, but the data can be homogeneous. A tuple's length is its number of elements and cannot change during program execution.

Creating Tuples

To create an empty tuple, use empty parentheses:

```
In [1]: student_tuple = ()

In [2]: student_tuple
Out[2]: ()

In [3]: len(student_tuple)
Out[3]: 0
```

Recall that you can pack a tuple by separating its values with commas:

```
In [4]: student_tuple = 'John', 'Green', 3.3

In [5]: student_tuple
Out[5]: ('John', 'Green', 3.3)

In [6]: len(student_tuple)
Out[6]: 3
```

When you output a tuple, Python always displays its contents in parentheses. You may surround a tuple's comma-separated list of values with optional parentheses:

```
In [7]: another_student_tuple = ('Mary', 'Red', 3.3)

In [8]: another_student_tuple
Out[8]: ('Mary', 'Red', 3.3)
```

The following code creates a one-element tuple:

```
In [9]: a_singleton_tuple = ('red',)  # note the comma

In [10]: a_singleton_tuple
Out[10]: ('red',)
```

The comma (`,`) that follows the string `'red'` identifies `a_singleton_tuple` as a tuple—the parentheses are optional. If the comma were omitted, the parentheses would be redundant, and `a_singleton_tuple` would simply refer to the string `'red'` rather than a tuple.

Accessing Tuple Elements

A tuple's elements, though related, are often of multiple types. Usually, you do not iterate over them. Rather, you access each individually. Like list indices, tuple indices start at 0. The following code creates `time_tuple` representing an hour, minute and second, displays the tuple, then uses its elements to calculate the number of seconds since midnight—note that we perform a *different* operation with each value in the tuple:

```
In [11]: time_tuple = (9, 16, 1)

In [12]: time_tuple
Out[12]: (9, 16, 1)

In [13]: time_tuple[0] * 3600 + time_tuple[1] * 60 + time_tuple[2]
Out[13]: 33361
```

Assigning a value to a tuple element causes a `TypeError`.

Adding Items to a String or Tuple

As with lists, the += augmented assignment statement can be used with strings and tuples, even though they're *immutable*. In the following code, after the two assignments, `tuple1` and `tuple2` refer to the *same* tuple object:

```
In [14]: tuple1 = (10, 20, 30)

In [15]: tuple2 = tuple1

In [16]: tuple2
Out[16]: (10, 20, 30)
```

Concatenating the tuple `(40, 50)` to `tuple1` creates a *new* tuple, then assigns a reference to it to the variable `tuple1`—`tuple2` still refers to the original tuple:

```
In [17]: tuple1 += (40, 50)

In [18]: tuple1
Out[18]: (10, 20, 30, 40, 50)

In [19]: tuple2
Out[19]: (10, 20, 30)
```

For a string or tuple, the item to the right of += must be a string or tuple, respectively—mixing types causes a `TypeError`.

Appending Tuples to Lists

You can use += to append a tuple to a list:

```
In [20]: numbers = [1, 2, 3, 4, 5]

In [21]: numbers += (6, 7)

In [22]: numbers
Out[22]: [1, 2, 3, 4, 5, 6, 7]
```

Tuples May Contain Mutable Objects

Let's create a `student_tuple` with a first name, last name and list of grades:

```
In [23]: student_tuple = ('Amanda', 'Blue', [98, 75, 87])
```

Even though the tuple is immutable, its list element is mutable:

```
In [24]: student_tuple[2][1] = 85

In [25]: student_tuple
Out[25]: ('Amanda', 'Blue', [98, 85, 87])
```

In the *double-subscripted name* `student_tuple[2][1]`, Python views `student_tuple[2]` as the element of the tuple containing the list `[98, 75, 87]`, then uses `[1]` to access the list element containing `75`. The assignment in snippet `[24]` replaces that grade with 85.

5.4 Unpacking Sequences

The previous chapter introduced tuple unpacking. You can unpack any sequence's elements by assigning the sequence to a comma-separated list of variables. A `ValueError` occurs if the number of variables to the left of the assignment symbol is not identical to the number of elements in the sequence on the right:

```
In [1]: student_tuple = ('Amanda', [98, 85, 87])

In [2]: first_name, grades = student_tuple

In [3]: first_name
Out[3]: 'Amanda'

In [4]: grades
Out[4]: [98, 85, 87]
```

The following code unpacks a string, a list and a sequence produced by `range`:

```
In [5]: first, second = 'hi'

In [6]: print(f'{first}  {second}')
h  i

In [7]: number1, number2, number3 = [2, 3, 5]

In [8]: print(f'{number1}  {number2}  {number3}')
2  3  5

In [9]: number1, number2, number3 = range(10, 40, 10)

In [10]: print(f'{number1}  {number2}  {number3}')
10  20  30
```

Swapping Values Via Packing and Unpacking

You can swap two variables' values using sequence packing and unpacking:

```
In [11]: number1 = 99

In [12]: number2 = 22

In [13]: number1, number2 = (number2, number1)

In [14]: print(f'number1 = {number1}; number2 = {number2}')
number1 = 22; number2 = 99
```

Accessing Indices and Values Safely with Built-in Function enumerate

Earlier, we called `range` to produce a sequence of index values, then accessed list elements in a `for` loop using the index values and the subscription operator (`[]`). This is error-prone because you could pass the wrong arguments to `range`. If any value produced by `range` is an out-of-bounds index, using it as an index causes an `IndexError`.

The preferred mechanism for accessing an element's index *and* value is the built-in function **`enumerate`**. This function receives an iterable and creates an iterator that, for each element, returns a tuple containing the element's index and value. The following code uses the built-in function **`list`** to create a list containing `enumerate`'s results:

```
In [15]: colors = ['red', 'orange', 'yellow']

In [16]: list(enumerate(colors))
Out[16]: [(0, 'red'), (1, 'orange'), (2, 'yellow')]
```

Similarly the built-in function **`tuple`** creates a tuple from a sequence:

```
In [17]: tuple(enumerate(colors))
Out[17]: ((0, 'red'), (1, 'orange'), (2, 'yellow'))
```

The following `for` loop unpacks each tuple returned by `enumerate` into the variables `index` and `value` and displays them:

```
In [18]: for index, value in enumerate(colors):
    ...:     print(f'{index}: {value}')
    ...:
0: red
1: orange
2: yellow
```

Creating a Primitive Bar Chart

The following script creates a primitive **bar chart** where each bar's length is made of asterisks (*) and is proportional to the list's corresponding element value. We use the function `enumerate` to access the list's indices and values safely. To run this example, change to this chapter's `ch05` examples folder, then enter:

```
ipython fig05_01.py
```

or, if you're in IPython already, use the command:

```
run fig05_01.py
```

```
# fig05_01.py
"""Displaying a bar chart"""
numbers = [19, 3, 15, 7, 11]

print('\nCreating a bar chart from numbers:')
print(f'Index{"Value":>8}   Bar')

for index, value in enumerate(numbers):
    print(f'{index:>5}{value:>8}   {"*" * value}')
```

```
Creating a bar chart from numbers:
Index   Value   Bar
    0      19   *******************
    1       3   ***
    2      15   ***************
    3       7   *******
    4      11   ***********
```

The `for` statement uses `enumerate` to get each element's index and value, then displays a formatted line containing the index, the element value and the corresponding bar of asterisks. The expression

```
"*" * value
```

creates a string consisting of `value` asterisks. When used with a sequence, the multiplication operator (`*`) *repeats* the sequence—in this case, the string `"*"`—`value` times. Later in this chapter, we'll use the open-source Seaborn and Matplotlib libraries to display a publication-quality bar chart visualization.

5.5 Sequence Slicing

You can slice sequences to create new sequences of the same type containing *subsets* of the original elements. Slice operations can modify mutable sequences—those that do *not* modify a sequence work identically for lists, tuples and strings.

Specifying a Slice with Starting and Ending Indices

Let's create a slice consisting of the elements at indices 2 through 5 of a list:

```
In [1]: numbers = [2, 3, 5, 7, 11, 13, 17, 19]

In [2]: numbers[2:6]
Out[2]: [5, 7, 11, 13]
```

The slice *copies* elements from the *starting index* to the left of the colon (`2`) up to, but not including, the *ending index* to the right of the colon (`6`). The original list is not modified.

Specifying a Slice with Only an Ending Index

If you omit the starting index, `0` is assumed. So, the slice `numbers[:6]` is equivalent to the slice `numbers[0:6]`:

```
In [3]: numbers[:6]
Out[3]: [2, 3, 5, 7, 11, 13]
```

```
In [4]: numbers[0:6]
Out[4]: [2, 3, 5, 7, 11, 13]
```

Specifying a Slice with Only a Starting Index

If you omit the ending index, Python assumes the sequence's length (`8` here), so snippet `[5]`'s slice contains the elements of `numbers` at indices `6` and `7`:

```
In [5]: numbers[6:]
Out[5]: [17, 19]

In [6]: numbers[6:len(numbers)]
Out[6]: [17, 19]
```

Specifying a Slice with No Indices

Omitting both the start and end indices copies the entire sequence:

```
In [7]: numbers[:]
Out[7]: [2, 3, 5, 7, 11, 13, 17, 19]
```

Though slices create new objects, slices make **shallow copies** of the elements—that is, they copy the elements' references but not the objects they point to. So, in the snippet above, the new list's elements refer to the *same objects* as the original list's elements, rather than to separate copies. In the "Array-Oriented Programming with NumPy" chapter, we'll explain *deep* copying, which actually copies the referenced objects themselves, and we'll point out when deep copying is preferred.

Slicing with Steps

The following code uses a *step* of `2` to create a slice with every other element of `numbers`:

```
In [8]: numbers[::2]
Out[8]: [2, 5, 11, 17]
```

We omitted the start and end indices, so `0` and `len(numbers)` are assumed, respectively.

Slicing with Negative Indices and Steps

You can use a negative step to select slices in *reverse* order. The following code concisely creates a new list in reverse order:

```
In [9]: numbers[::-1]
Out[9]: [19, 17, 13, 11, 7, 5, 3, 2]
```

This is equivalent to:

```
In [10]: numbers[-1:-9:-1]
Out[10]: [19, 17, 13, 11, 7, 5, 3, 2]
```

Modifying Lists Via Slices

You can modify a list by assigning to a slice of it—the rest of the list is unchanged. The following code replaces `numbers`' first three elements, leaving the rest unchanged:

```
In [11]: numbers[0:3] = ['two', 'three', 'five']

In [12]: numbers
Out[12]: ['two', 'three', 'five', 7, 11, 13, 17, 19]
```

The following deletes only the first three elements of `numbers` by assigning an *empty* list to the three-element slice:

```
In [13]: numbers[0:3] = []

In [14]: numbers
Out[14]: [7, 11, 13, 17, 19]
```

The following assigns a list's elements to a slice of every other element of `numbers`:

```
In [15]: numbers = [2, 3, 5, 7, 11, 13, 17, 19]

In [16]: numbers[::2] = [100, 100, 100, 100]

In [17]: numbers
Out[17]: [100, 3, 100, 7, 100, 13, 100, 19]

In [18]: id(numbers)
Out[18]: 4434456648
```

Let's delete all the elements in `numbers`, leaving the *existing* list empty:

```
In [19]: numbers[:] = []

In [20]: numbers
Out[20]: []

In [21]: id(numbers)
Out[21]: 4434456648
```

Deleting `numbers`' contents (snippet `[19]`) is different from assigning `numbers` a *new* empty list `[]` (snippet `[22]`). To prove this, we display `numbers`' identity after each operation. The identities are different, so they represent separate objects in memory:

```
In [22]: numbers = []

In [23]: numbers
Out[23]: []

In [24]: id(numbers)
Out[24]: 4406030920
```

When you assign a new object to a variable (as in snippet `[21]`), the original object will be garbage collected if no other variables refer to it.

5.6 `del` Statement

The **`del` statement** also can be used to remove elements from a list and to delete variables from the interactive session. You can remove the element at any valid index or the element(s) from any valid slice.

Deleting the Element at a Specific List Index

Let's create a list, then use `del` to remove its last element:

```
In [1]: numbers = list(range(0, 10))

In [2]: numbers
Out[2]: [0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
```

```
In [3]: del numbers[-1]

In [4]: numbers
Out[4]: [0, 1, 2, 3, 4, 5, 6, 7, 8]
```

Deleting a Slice from a List

The following deletes the list's first two elements:

```
In [5]: del numbers[0:2]

In [6]: numbers
Out[6]: [2, 3, 4, 5, 6, 7, 8]
```

The following uses a step in the slice to delete every other element from the entire list:

```
In [7]: del numbers[::2]

In [8]: numbers
Out[8]: [3, 5, 7]
```

Deleting a Slice Representing the Entire List

The following code deletes all of the list's elements:

```
In [9]: del numbers[:]

In [10]: numbers
Out[10]: []
```

Deleting a Variable from the Current Session

The `del` statement can delete any variable. Let's delete `numbers` from the interactive session, then attempt to display the variable's value, causing a `NameError`:

```
In [11]: del numbers

In [12]: numbers
------------------------------------------------------------------------
NameError                                 Traceback (most recent call last)
<ipython-input-12-426f8401232b> in <module>()
----> 1 numbers

NameError: name 'numbers' is not defined
```

5.7 Passing Lists to Functions

In the last chapter, we mentioned that all objects are passed by reference and demonstrated passing an immutable object as a function argument. Here, we discuss references further by examining what happens when a program passes a mutable list object to a function.

Passing an Entire List to a Function

Consider the function `modify_elements`, which receives a reference to a list and multiplies each of the list's element values by `2`:

```
In [1]: def modify_elements(items):
   ...:     """"Multiplies all element values in items by 2."""
   ...:     for i in range(len(items)):
   ...:         items[i] *= 2
   ...:

In [2]: numbers = [10, 3, 7, 1, 9]

In [3]: modify_elements(numbers)

In [4]: numbers
Out[4]: [20, 6, 14, 2, 18]
```

Function `modify_elements`' `items` parameter receives a reference to the *original* list, so the statement in the loop's suite modifies each element in the original list object.

Passing a Tuple to a Function

When you pass a tuple to a function, attempting to modify the tuple's immutable elements results in a `TypeError`:

```
In [5]: numbers_tuple = (10, 20, 30)

In [6]: numbers_tuple
Out[6]: (10, 20, 30)

In [7]: modify_elements(numbers_tuple)
---------------------------------------------------------------------------
TypeError                                 Traceback (most recent call last)
<ipython-input-7-9339741cd595> in <module>()
----> 1 modify_elements(numbers_tuple)

<ipython-input-1-27acb8f8f44c> in modify_elements(items)
      2     """"Multiplies all element values in items by 2."""
      3     for i in range(len(items)):
----> 4         items[i] *= 2
      5
      6

TypeError: 'tuple' object does not support item assignment
```

Recall that tuples may contain mutable objects, such as lists. Those objects still can be modified when a tuple is passed to a function.

A Note Regarding Tracebacks

The previous traceback shows the *two* snippets that led to the `TypeError`. The first is snippet `[7]`'s function call. The second is snippet `[1]`'s function definition. Line numbers precede each snippet's code. We've demonstrated mostly single-line snippets. When an exception occurs in such a snippet, it's always preceded by `----> 1`, indicating that line 1 (the snippet's only line) caused the exception. Multiline snippets like the definition of `modify_elements` show consecutive line numbers starting at 1. The notation `----> 4` above indicates that the exception occurred in line 4 of `modify_elements`. No matter how long the traceback is, the last line of code with `---->` caused the exception.

5.8 Sorting Lists

Sorting enables you to arrange data either in ascending or descending order.

Sorting a List in Ascending Order

List method **sort** *modifies* a list to arrange its elements in ascending order:

```
In [1]: numbers = [10, 3, 7, 1, 9, 4, 2, 8, 5, 6]

In [2]: numbers.sort()

In [3]: numbers
Out[3]: [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]
```

Sorting a List in Descending Order

To sort a list in descending order, call list method `sort` with the optional keyword argument **reverse** set to `True` (`False` is the default):

```
In [4]: numbers.sort(reverse=True)

In [5]: numbers
Out[5]: [10, 9, 8, 7, 6, 5, 4, 3, 2, 1]
```

Built-In Function sorted

Built-in function **sorted** *returns a new list* containing the sorted elements of its argument *sequence*—the original sequence is *unmodified*. The following code demonstrates function `sorted` for a list, a string and a tuple:

```
In [6]: numbers = [10, 3, 7, 1, 9, 4, 2, 8, 5, 6]

In [7]: ascending_numbers = sorted(numbers)

In [8]: ascending_numbers
Out[8]: [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]

In [9]: numbers
Out[9]: [10, 3, 7, 1, 9, 4, 2, 8, 5, 6]

In [10]: letters = 'fadgchjebi'

In [11]: ascending_letters = sorted(letters)

In [12]: ascending_letters
Out[12]: ['a', 'b', 'c', 'd', 'e', 'f', 'g', 'h', 'i', 'j']

In [13]: letters
Out[13]: 'fadgchjebi'

In [14]: colors = ('red', 'orange', 'yellow', 'green', 'blue')

In [15]: ascending_colors = sorted(colors)

In [16]: ascending_colors
Out[16]: ['blue', 'green', 'orange', 'red', 'yellow']

In [17]: colors
Out[17]: ('red', 'orange', 'yellow', 'green', 'blue')
```

Use the optional keyword argument `reverse` with the value `True` to sort the elements in descending order.

5.9 Searching Sequences

Often, you'll want to determine whether a sequence (such as a list, tuple or string) contains a value that matches a particular **key** value. **Searching** is the process of locating a key.

List Method `index`

List method **`index`** takes as an argument a search key—the value to locate in the list—then searches through the list from index 0 and returns the index of the *first* element that matches the search key:

```
In [1]: numbers = [3, 7, 1, 4, 2, 8, 5, 6]

In [2]: numbers.index(5)
Out[2]: 6
```

A `ValueError` occurs if the value you're searching for is not in the list.

Specifying the Starting Index of a Search

Using method `index`'s optional arguments, you can search a subset of a list's elements. You can use *= to *multiply a sequence*—that is, append a sequence to itself multiple times. After the following snippet, `numbers` contains two copies of the original list's contents:

```
In [3]: numbers *= 2

In [4]: numbers
Out[4]: [3, 7, 1, 4, 2, 8, 5, 6, 3, 7, 1, 4, 2, 8, 5, 6]
```

The following code searches the updated list for the value `5` starting from index `7` and continuing through the end of the list:

```
In [5]: numbers.index(5, 7)
Out[5]: 14
```

Specifying the Starting and Ending Indices of a Search

Specifying the starting and ending indices causes `index` to search from the starting index up to but not including the ending index location. The call to `index` in snippet `[5]`:

```
numbers.index(5, 7)
```

assumes the length of `numbers` as its optional third argument and is equivalent to:

```
numbers.index(5, 7, len(numbers))
```

The following looks for the value `7` in the range of elements with indices `0` through `3`:

```
In [6]: numbers.index(7, 0, 4)
Out[6]: 1
```

Operators `in` and `not in`

Operator `in` tests whether its right operand's iterable contains the left operand's value:

```
In [7]: 1000 in numbers
Out[7]: False
```

```
In [8]: 5 in numbers
Out[8]: True
```

Similarly, operator `not in` tests whether its right operand's iterable does *not* contain the left operand's value:

```
In [9]: 1000 not in numbers
Out[9]: True

In [10]: 5 not in numbers
Out[10]: False
```

Using Operator `in` to Prevent a `ValueError`

You can use the operator `in` to ensure that calls to method `index` do not result in `ValueErrors` for search keys that are not in the corresponding sequence:

```
In [11]: key = 1000

In [12]: if key in numbers:
    ...:     print(f'found {key} at index {numbers.index(search_key)}')
    ...: else:
    ...:     print(f'{key} not found')
    ...:
1000 not found
```

Built-In Functions `any` and `all`

Sometimes you simply need to know whether *any* item in an iterable is `True` or whether *all* the items are `True`. The built-in function **`any`** returns `True` if any item in its iterable argument is `True`. The built-in function **`all`** returns `True` if all items in its iterable argument are `True`. Recall that nonzero values are `True` and 0 is `False`. Non-empty iterable objects also evaluate to `True`, whereas any empty iterable evaluates to `False`. Functions `any` and `all` are additional examples of internal iteration in functional-style programming.

5.10 Other List Methods

Lists also have methods that add and remove elements. Consider the list `color_names`:

```
In [1]: color_names = ['orange', 'yellow', 'green']
```

Inserting an Element at a Specific List Index

Method **`insert`** adds a new item at a specified index. The following inserts `'red'` at index `0`:

```
In [2]: color_names.insert(0, 'red')

In [3]: color_names
Out[3]: ['red', 'orange', 'yellow', 'green']
```

Adding an Element to the End of a List

You can add a new item to the end of a list with method **`append`**:

```
In [4]: color_names.append('blue')

In [5]: color_names
Out[5]: ['red', 'orange', 'yellow', 'green', 'blue']
```

Adding All the Elements of a Sequence to the End of a List

Use list method **extend** to add all the elements of another sequence to the end of a list:

```
In [6]: color_names.extend(['indigo', 'violet'])

In [7]: color_names
Out[7]: ['red', 'orange', 'yellow', 'green', 'blue', 'indigo', 'violet']
```

This is the equivalent of using +=. The following code adds all the characters of a string then all the elements of a tuple to a list:

```
In [8]: sample_list = []

In [9]: s = 'abc'

In [10]: sample_list.extend(s)

In [11]: sample_list
Out[11]: ['a', 'b', 'c']

In [12]: t = (1, 2, 3)

In [13]: sample_list.extend(t)

In [14]: sample_list
Out[14]: ['a', 'b', 'c', 1, 2, 3]
```

Rather than creating a temporary variable, like t, to store a tuple before appending it to a list, you might want to pass a tuple directly to extend. In this case, the tuple's parentheses are required, because extend expects one iterable argument:

```
In [15]: sample_list.extend((4, 5, 6))  # note the extra parentheses

In [16]: sample_list
Out[16]: ['a', 'b', 'c', 1, 2, 3, 4, 5, 6]
```

A TypeError occurs if you omit the required parentheses.

Removing the First Occurrence of an Element in a List

Method **remove** deletes the first element with a specified value—a ValueError occurs if remove's argument is not in the list:

```
In [17]: color_names.remove('green')

In [18]: color_names
Out[18]: ['red', 'orange', 'yellow', 'blue', 'indigo', 'violet']
```

Emptying a List

To delete all the elements in a list, call method **clear**:

```
In [19]: color_names.clear()

In [20]: color_names
Out[20]: []
```

This is the equivalent of the previously shown slice assignment

```
color_names[:] = []
```

Counting the Number of Occurrences of an Item

List method **count** searches for its argument and returns the number of times it is found:

```
In [21]: responses = [1, 2, 5, 4, 3, 5, 2, 1, 3, 3,
    ...:              1, 4, 3, 3, 3, 2, 3, 3, 2, 2]
    ...:

In [22]: for i in range(1, 6):
    ...:     print(f'{i} appears {responses.count(i)} times in responses')
    ...:
1 appears 3 times in responses
2 appears 5 times in responses
3 appears 8 times in responses
4 appears 2 times in responses
5 appears 2 times in responses
```

Reversing a List's Elements

List method **reverse** reverses the contents of a list in place, rather than creating a reversed copy, as we did with a slice previously:

```
In [23]: color_names = ['red', 'orange', 'yellow', 'green', 'blue']

In [24]: color_names.reverse()

In [25]: color_names
Out[25]: ['blue', 'green', 'yellow', 'orange', 'red']
```

Copying a List

List method copy returns a *new* list containing a *shallow* copy of the original list:

```
In [26]: copied_list = color_names.copy()

In [27]: copied_list
Out[27]: ['blue', 'green', 'yellow', 'orange', 'red']
```

This is equivalent to the previously demonstrated slice operation:

```
copied_list = color_names[:]
```

5.11 Simulating Stacks with Lists

The preceding chapter introduced the function-call stack. Python does not have a built-in stack type, but you can think of a stack as a constrained list. You *push* using list method append, which adds a new element to the *end* of the list. You *pop* using list method **pop** with no arguments, which removes and returns the item at the *end* of the list.

Let's create an empty list called stack, push (append) two strings onto it, then pop the strings to confirm they're retrieved in last-in, first-out (LIFO) order:

```
In [1]: stack = []

In [2]: stack.append('red')

In [3]: stack
Out[3]: ['red']

In [4]: stack.append('green')
In [5]: stack
Out[5]: ['red', 'green']

In [6]: stack.pop()
Out[6]: 'green'

In [7]: stack
Out[7]: ['red']

In [8]: stack.pop()
Out[8]: 'red'

In [9]: stack
Out[9]: []

In [10]: stack.pop()
---------------------------------------------------------------------------
IndexError                                Traceback (most recent call last)
<ipython-input-10-50ea7ec13fbe> in <module>()
----> 1 stack.pop()

IndexError: pop from empty list
```

For each pop snippet, the value that pop removes and returns is displayed. Popping from an empty stack causes an IndexError, just like accessing a nonexistent list element with []. To prevent an IndexError, ensure that len(stack) is greater than 0 before calling pop. You can run out of memory if you keep pushing items faster than you pop them.

You also can use a list to simulate another popular collection called a **queue** in which you insert at the back and delete from the front. Items are retrieved from queues in **first-in, first-out (FIFO) order**.

5.12 List Comprehensions

Here, we continue discussing *functional-style* features with **list comprehensions**—a concise and convenient notation for creating new lists. List comprehensions can replace many for statements that iterate over existing sequences and create new lists, such as:

```
In [1]: list1 = []

In [2]: for item in range(1, 6):
   ...:     list1.append(item)
   ...:

In [3]: list1
Out[3]: [1, 2, 3, 4, 5]
```

Using a List Comprehension to Create a List of Integers

We can accomplish the same task in a single line of code with a list comprehension:

```
In [4]: list2 = [item for item in range(1, 6)]

In [5]: list2
Out[5]: [1, 2, 3, 4, 5]
```

Like snippet [2]'s for statement, the list comprehension's **for clause**

```
for item in range(1, 6)
```

iterates over the sequence produced by range(1, 6). For each item, the list comprehension evaluates the expression to the left of the for clause and places the expression's value (in this case, the item itself) in the new list. Snippet [4]'s particular comprehension could have been expressed more concisely using the function list:

```
list2 = list(range(1, 6))
```

Mapping: Performing Operations in a List Comprehension's Expression

A list comprehension's expression can perform tasks, such as calculations, that **map** elements to new values (possibly of different types). Mapping is a common functional-style programming operation that produces a result with the *same* number of elements as the original data being mapped. The following comprehension maps each value to its cube with the expression item ** 3:

```
In [6]: list3 = [item ** 3 for item in range(1, 6)]

In [7]: list3
Out[7]: [1, 8, 27, 64, 125]
```

Filtering: List Comprehensions with if Clauses

Another common functional-style programming operation is **filtering** elements to select only those that match a condition. This typically produces a list with *fewer* elements than the data being filtered. To do this in a list comprehension, use the **if clause**. The following includes in list4 only the even values produced by the for clause:

```
In [8]: list4 = [item for item in range(1, 11) if item % 2 == 0]

In [9]: list4
Out[9]: [2, 4, 6, 8, 10]
```

List Comprehension That Processes Another List's Elements

The for clause can process any iterable. Let's create a list of lowercase strings and use a list comprehension to create a new list containing their uppercase versions:

```
In [10]: colors = ['red', 'orange', 'yellow', 'green', 'blue']

In [11]: colors2 = [item.upper() for item in colors]

In [12]: colors2
Out[12]: ['RED', 'ORANGE', 'YELLOW', 'GREEN', 'BLUE']

In [13]: colors
Out[13]: ['red', 'orange', 'yellow', 'green', 'blue']
```

5.13 Generator Expressions

A **generator expression** is similar to a list comprehension, but creates an iterable **generator object** that produces values *on demand*. This is known as **lazy evaluation**. List comprehensions use **greedy evaluation**—they create lists *immediately* when you execute them. For large numbers of items, creating a list can take substantial memory and time. So generator expressions can reduce your program's memory consumption and improve performance if the whole list is not needed at once.

Generator expressions have the same capabilities as list comprehensions, but you define them in parentheses instead of square brackets. The generator expression in snippet [2] squares and returns only the odd values in numbers:

```
In [1]: numbers = [10, 3, 7, 1, 9, 4, 2, 8, 5, 6]

In [2]: for value in (x ** 2 for x in numbers if x % 2 != 0):
   ...:     print(value, end='  ')
   ...:
9  49  1  81  25
```

To show that a generator expression does not create a list, let's assign the preceding snippet's generator expression to a variable and evaluate the variable:

```
In [3]: squares_of_odds = (x ** 2 for x in numbers if x % 2 != 0)

In [3]: squares_of_odds
Out[3]: <generator object <genexpr> at 0x1085e84c0>
```

The text "generator object <genexpr>" indicates that square_of_odds is a generator object that was created from a generator expression (genexpr).

5.14 Filter, Map and Reduce

The preceding section introduced several functional-style features—list comprehensions, filtering and mapping. Here we demonstrate the built-in filter and map functions for filtering and mapping, respectively. We continue discussing reductions in which you process a collection of elements into a *single* value, such as their count, total, product, average, minimum or maximum.

Filtering a Sequence's Values with the Built-In filter Function

Let's use built-in function **filter** to obtain the odd values in numbers:

```
In [1]: numbers = [10, 3, 7, 1, 9, 4, 2, 8, 5, 6]

In [2]: def is_odd(x):
   ...:     """Returns True only if x is odd."""
   ...:     return x % 2 != 0
   ...:

In [3]: list(filter(is_odd, numbers))
Out[3]: [3, 7, 1, 9, 5]
```

Like data, Python functions are objects that you can assign to variables, pass to other functions and return from functions. Functions that receive other functions as arguments are a functional-style capability called **higher-order functions**. For example, filter's first argument must be a function that receives one argument and returns True if the value should be included in the result. The function is_odd returns True if its argument is odd. The filter function calls is_odd once for each value in its second argument's iterable (numbers). Higher-order functions may also return a function as a result.

Function `filter` returns an iterator, so `filter`'s results are not produced until you iterate through them. This is another example of lazy evaluation. In snippet `[3]`, function `list` iterates through the results and creates a list containing them. We can obtain the same results as above by using a list comprehension with an `if` clause:

```
In [4]: [item for item in numbers if is_odd(item)]
Out[4]: [3, 7, 1, 9, 5]
```

Using a `lambda` Rather than a Function

For simple functions like `is_odd` that `return` only a *single expression's value*, you can use a **lambda expression** (or simply a **lambda**) to define the function inline where it's needed—typically as it's passed to another function:

```
In [5]: list(filter(lambda x: x % 2 != 0, numbers))
Out[5]: [3, 7, 1, 9, 5]
```

We pass `filter`'s return value (an iterator) to function `list` here to convert the results to a list and display them.

A lambda expression is an *anonymous function*—that is, a *function without a name*. In the `filter` call

```
filter(lambda x: x % 2 != 0, numbers)
```

the first argument is the lambda

```
lambda x: x % 2 != 0
```

A lambda begins with the **`lambda`** keyword followed by a comma-separated parameter list, a colon (`:`) and an expression. In this case, the parameter list has one parameter named `x`. A `lambda` *implicitly* returns its expression's value. So any simple function of the form

```
def function_name(parameter_list):
    return expression
```

may be expressed as a more concise `lambda` of the form

```
lambda parameter_list: expression
```

Mapping a Sequence's Values to New Values

Let's use built-in function **`map`** with a `lambda` to square each value in `numbers`:

```
In [6]: numbers
Out[6]: [10, 3, 7, 1, 9, 4, 2, 8, 5, 6]

In [7]: list(map(lambda x: x ** 2, numbers))
Out[7]: [100, 9, 49, 1, 81, 16, 4, 64, 25, 36]
```

Function `map`'s first argument is a function that receives one value and returns a new value—in this case, a `lambda` that squares its argument. The second argument is an iterable of values to map. Function `map` uses lazy evaluation. So, we pass to the `list` function the iterator that `map` returns. This enables us to iterate through and create a list of the mapped values. Here's an equivalent list comprehension:

```
In [8]: [item ** 2 for item in numbers]
Out[8]: [100, 9, 49, 1, 81, 16, 4, 64, 25, 36]
```

Combining filter and map

You can combine the preceding filter and map operations as follows:

```
In [9]: list(map(lambda x: x ** 2,
   ...:          filter(lambda x: x % 2 != 0, numbers)))
   ...:
Out[9]: [9, 49, 1, 81, 25]
```

There is a lot going on in snippet [9], so let's take a closer look at it. First, filter returns an iterable representing only the odd values of numbers. Then map returns an iterable representing the squares of the filtered values. Finally, list uses map's iterable to create the list. You might prefer the following list comprehension to the preceding snippet:

```
In [10]: [x ** 2 for x in numbers if x % 2 != 0]
Out[10]: [9, 49, 1, 81, 25]
```

For each value of x in numbers, the expression x ** 2 is performed only if the condition x % 2 != 0 is True.

Reduction: Totaling the Elements of a Sequence with sum

As you know reductions process a sequence's elements into a single value. You've performed reductions with the built-in functions len, sum, min and max. You also can create custom reductions using the functools module's reduce function. See https://docs.python.org/3/library/functools.html for a code example. When we investigate big data and Hadoop in Chapter 16, we'll demonstrate MapReduce programming, which is based on the filter, map and reduce operations in functional-style programming.

5.15 Other Sequence Processing Functions

Python provides other built-in functions for manipulating sequences.

Finding the Minimum and Maximum Values Using a Key Function

We've previously shown the built-in reduction functions min and max using arguments, such as ints or lists of ints. Sometimes you'll need to find the minimum and maximum of more complex objects, such as strings. Consider the following comparison:

```
In [1]: 'Red' < 'orange'
Out[1]: True
```

The letter 'R' "comes after" 'o' in the alphabet, so you might expect 'Red' to be less than 'orange' and the condition above to be False. However, strings are compared by their characters' underlying *numerical values*, and lowercase letters have *higher* numerical values than uppercase letters. You can confirm this with built-in function **ord**, which returns the numerical value of a character:

```
In [2]: ord('R')
Out[2]: 82

In [3]: ord('o')
Out[3]: 111
```

Consider the list colors, which contains strings with uppercase and lowercase letters:

```
In [4]: colors = ['Red', 'orange', 'Yellow', 'green', 'Blue']
```

Let's assume that we'd like to determine the minimum and maximum strings using *alphabetical* order, not *numerical* (lexicographical) order. If we arrange colors alphabetically

```
'Blue', 'green', 'orange', 'Red', 'Yellow'
```

you can see that 'Blue' is the minimum (that is, closest to the beginning of the alphabet), and 'Yellow' is the maximum (that is, closest to the end of the alphabet).

Since Python compares strings using numerical values, you must first convert each string to all lowercase or all uppercase letters. Then their numerical values will also represent *alphabetical* ordering. The following snippets enable min and max to determine the minimum and maximum strings alphabetically:

```
In [5]: min(colors, key=lambda s: s.lower())
Out[5]: 'Blue'

In [6]: max(colors, key=lambda s: s.lower())
Out[6]: 'Yellow'
```

The key keyword argument must be a one-parameter function that returns a value. In this case, it's a lambda that calls string method **lower** to get a string's lowercase version. Functions min and max call the key argument's function for each element and use the results to compare the elements.

Iterating Backward Through a Sequence

Built-in function **reversed** returns an iterator that enables you to iterate over a sequence's values backward. The following list comprehension creates a new list containing the squares of numbers' values in reverse order:

```
In [7]: numbers = [10, 3, 7, 1, 9, 4, 2, 8, 5, 6]

In [7]: reversed_numbers = [item for item in reversed(numbers)]

In [8]: reversed_numbers
Out[8]: [36, 25, 64, 4, 16, 81, 1, 49, 9, 100]
```

Combining Iterables into Tuples of Corresponding Elements

Built-in function **zip** enables you to iterate over *multiple* iterables of data at the *same* time. The function receives as arguments any number of iterables and returns an iterator that produces tuples containing the elements at the same index in each. For example, snippet [11]'s call to zip produces the tuples ('Bob', 3.5), ('Sue', 4.0) and ('Amanda', 3.75) consisting of the elements at index 0, 1 and 2 of each list, respectively:

```
In [9]: names = ['Bob', 'Sue', 'Amanda']

In [10]: grade_point_averages = [3.5, 4.0, 3.75]

In [11]: for name, gpa in zip(names, grade_point_averages):
    ...:     print(f'Name={name}; GPA={gpa}')
    ...:
Name=Bob; GPA=3.5
Name=Sue; GPA=4.0
Name=Amanda; GPA=3.75
```

We unpack each tuple into name and gpa and display them. Function zip's shortest argument determines the number of tuples produced. Here both have the same length.

5.16 Two-Dimensional Lists

Lists can contain other lists as elements. A typical use of such nested (or multidimensional) lists is to represent **tables** of values consisting of information arranged in **rows** and **columns**. To identify a particular table element, we specify *two* indices—by convention, the first identifies the element's row, the second the element's column.

Lists that require two indices to identify an element are called **two-dimensional lists** (or **double-indexed lists** or **double-subscripted lists**). Multidimensional lists can have more than two indices. Here, we introduce two-dimensional lists.

Creating a Two-Dimensional List

Consider a two-dimensional list with three rows and four columns (i.e., a 3-by-4 list) that might represent the grades of three students who each took four exams in a course:

```
In [1]: a = [[77, 68, 86, 73], [96, 87, 89, 81], [70, 90, 86, 81]]
```

Writing the list as follows makes its row and column tabular structure clearer:

```
a = [[77, 68, 86, 73],  # first student's grades
     [96, 87, 89, 81],  # second student's grades
     [70, 90, 86, 81]]  # third student's grades
```

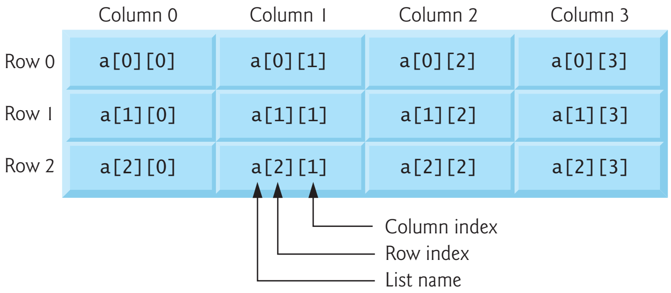
Illustrating a Two-Dimensional List

The diagram below shows the list a, with its rows and columns of exam grade values:

	Column 0	Column 1	Column 2	Column 3
Row 0	77	68	86	73
Row 1	96	87	89	81
Row 2	70	90	86	81

Identifying the Elements in a Two-Dimensional List

The following diagram shows the names of list a's elements:



	Column 0	Column 1	Column 2	Column 3
Row 0	a[0][0]	a[0][1]	a[0][2]	a[0][3]
Row 1	a[1][0]	a[1][1]	a[1][2]	a[1][3]
Row 2	a[2][0]	a[2][1]	a[2][2]	a[2][3]

Every element is identified by a name of the form a[*i*][*j*]—a is the list's name, and *i* and *j* are the indices that uniquely identify each element's row and column, respectively. The element names in row 0 all have 0 as the first index. The element names in column 3 all have 3 as the second index.

In the two-dimensional list a:

- 77, 68, 86 and 73 initialize a[0][0], a[0][1], a[0][2] and a[0][3], respectively,
- 96, 87, 89 and 81 initialize a[1][0], a[1][1], a[1][2] and a[1][3], respectively, and
- 70, 90, 86 and 81 initialize a[2][0], a[2][1], a[2][2] and a[2][3], respectively.

A list with *m* rows and *n* columns is called an **m-by-n list** and has *m* × *n* elements.

The following nested for statement outputs the rows of the preceding two-dimensional list one row at a time:

```
In [2]: for row in a:
   ...:     for item in row:
   ...:         print(item, end=' ')
   ...:     print()
   ...:
77 68 86 73
96 87 89 81
70 90 86 81
```

How the Nested Loops Execute

Let's modify the nested loop to display the list's name and the row and column indices and value of each element:

```
In [3]: for i, row in enumerate(a):
   ...:     for j, item in enumerate(row):
   ...:         print(f'a[{i}][{j}]={item} ', end=' ')
   ...:     print()
   ...:
a[0][0]=77  a[0][1]=68  a[0][2]=86  a[0][3]=73
a[1][0]=96  a[1][1]=87  a[1][2]=89  a[1][3]=81
a[2][0]=70  a[2][1]=90  a[2][2]=86  a[2][3]=81
```

The outer for statement iterates over the two-dimensional list's rows one row at a time. During each iteration of the outer for statement, the inner for statement iterates over *each* column in the current row. So in the first iteration of the outer loop, row 0 is

```
[77, 68, 86, 73]
```

and the nested loop iterates through this list's four elements a[0][0]=77, a[0][1]=68, a[0][2]=86 and a[0][3]=73.

In the second iteration of the outer loop, row 1 is

```
[96, 87, 89, 81]
```

and the nested loop iterates through this list's four elements a[1][0]=96, a[1][1]=87, a[1][2]=89 and a[1][3]=81.

In the third iteration of the outer loop, row 2 is

```
[70, 90, 86, 81]
```

and the nested loop iterates through this list's four elements a[2][0]=70, a[2][1]=90, a[2][2]=86 and a[2][3]=81.

In the "Array-Oriented Programming with NumPy" chapter, we'll cover the NumPy library's ndarray collection and the Pandas library's DataFrame collection. These enable you to manipulate multidimensional collections more concisely and conveniently than the two-dimensional list manipulations you've seen in this section.

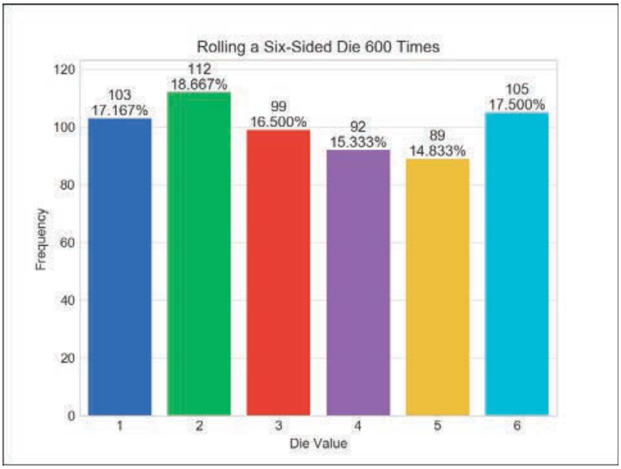
5.17 Intro to Data Science: Simulation and Static Visualizations

The last few chapters' Intro to Data Science sections discussed basic descriptive statistics. Here, we focus on visualizations, which help you "get to know" your data. Visualizations give you a powerful way to understand data that goes beyond simply looking at raw data.

We use two open-source visualization libraries—Seaborn and Matplotlib—to display *static* bar charts showing the final results of a six-sided-die-rolling simulation. The **Seaborn visualization library** is built over the **Matplotlib visualization library** and simplifies many Matplotlib operations. We'll use aspects of both libraries, because some of the Seaborn operations return objects from the Matplotlib library. In the next chapter's Intro to Data Science section, we'll make things "come alive" with *dynamic visualizations*.

5.17.1 Sample Graphs for 600, 60,000 and 6,000,000 Die Rolls

The screen capture below shows a vertical bar chart that for 600 die rolls summarizes the frequencies with which each of the six faces appear, and their percentages of the total. Seaborn refers to this type of graph as a **bar plot**:



Here we expect about 100 occurrences of each die face. However, with such a small number of rolls, none of the frequencies is exactly 100 (though several are close) and most of the percentages are not close to 16.667% (about 1/6th). As we run the simulation for 60,000 die rolls, the bars will become much closer in size. At 6,000,000 die rolls, they'll appear to be exactly the same size. This is the "law of large numbers" at work. The next chapter will show the lengths of the bars changing dynamically.

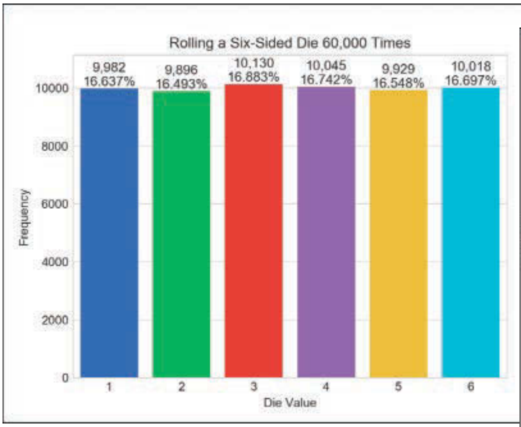
We'll discuss how to control the plot's appearance and contents, including:

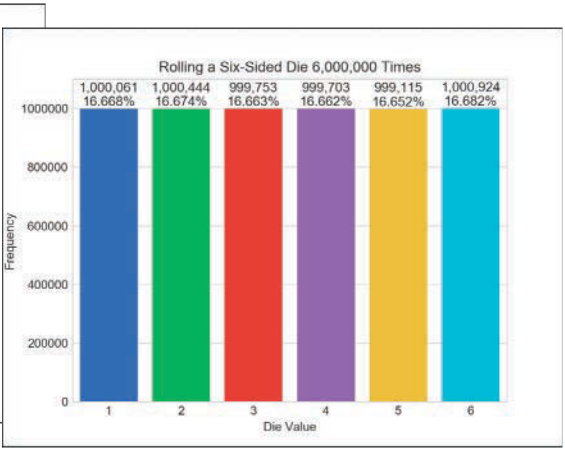
- the graph title inside the window (**Rolling a Six-Sided Die 600 Times**),
- the descriptive labels **Die Value** for the *x*-axis and **Frequency** for the *y*-axis,

- the text displayed above each bar, representing the *frequency* and *percentage* of the total rolls, and
- the bar colors.

We’ll use various Seaborn default options. For example, Seaborn determines the text labels along the *x*-axis from the die face values 1–6 and the text labels along the *y*-axis from the actual die frequencies. Behind the scenes, Matplotlib determines the positions and sizes of the bars, based on the window size and the magnitudes of the values the bars represent. It also positions the **Frequency** axis’s numeric labels based on the actual die frequencies that the bars represent. There are many more features you can customize. You should tweak these attributes to your personal preferences.

The first screen capture below shows the results for 60,000 die rolls—imagine trying to do this by hand. In this case, we expect about 10,000 of each face. The second screen capture below shows the results for 6,000,000 rolls—surely something you’d never do by hand! In this case, we expect about 1,000,000 of each face, and the frequency bars appear to be identical in length (they’re close but not exactly the same length). Note that with more die rolls, the frequency percentages are much closer to the expected 16.667%.





5.17.2 Visualizing Die-Roll Frequencies and Percentages

In this section, you’ll interactively develop the bar plots shown in the preceding section.

Launching IPython for Interactive Matplotlib Development

IPython has built-in support for interactively developing Matplotlib graphs, which you also need to develop Seaborn graphs. Simply launch IPython with the command:

```
ipython --matplotlib
```

Importing the Libraries

First, let’s import the libraries we’ll use:

```
In [1]: import matplotlib.pyplot as plt

In [2]: import numpy as np
In [3]: import random

In [4]: import seaborn as sns
```

1. The **matplotlib.pyplot module** contains the Matplotlib library's graphing capabilities that we use. This module typically is imported with the name `plt`.
2. The NumPy (Numerical Python) library includes the function `unique` that we'll use to summarize the die rolls. The **numpy module** typically is imported as `np`.
3. The `random` module contains Python's random-number generation functions.
4. The **seaborn module** contains the Seaborn library's graphing capabilities we use. This module typically is imported with the name `sns`. Search for why this curious abbreviation was chosen.

Rolling the Die and Calculating Die Frequencies

Next, let's use a *list comprehension* to create a list of 600 random die values, then use NumPy's **unique** function to determine the unique roll values (most likely all six possible face values) and their frequencies:

```
In [5]: rolls = [random.randrange(1, 7) for i in range(600)]

In [6]: values, frequencies = np.unique(rolls, return_counts=True)
```

The NumPy library provides the high-performance **ndarray** collection, which is typically much faster than lists.[1] Though we do not use `ndarray` directly here, the NumPy `unique` function expects an `ndarray` argument and returns an `ndarray`. If you pass a list (like `rolls`), NumPy converts it to an `ndarray` for better performance. The `ndarray` that `unique` returns we'll simply assign to a variable for use by a Seaborn plotting function.

Specifying the keyword argument **return_counts**`=True` tells `unique` to count each unique value's number of occurrences. In this case, `unique` returns a tuple of two one-dimensional `ndarrays` containing the sorted unique values and the corresponding frequencies, respectively. We unpack the tuple's `ndarrays` into the variables `values` and `frequencies`. If `return_counts` is `False`, only the list of unique values is returned.

Creating the Initial Bar Plot

Let's create the bar plot's title, set its style, then graph the die faces and frequencies:

```
In [7]: title = f'Rolling a Six-Sided Die {len(rolls):,} Times'

In [8]: sns.set_style('whitegrid')

In [9]: axes = sns.barplot(x=values, y=frequencies, palette='bright')
```

Snippet `[7]`'s f-string includes the number of die rolls in the bar plot's title. The comma (,) format specifier in

```
{len(rolls):,}
```

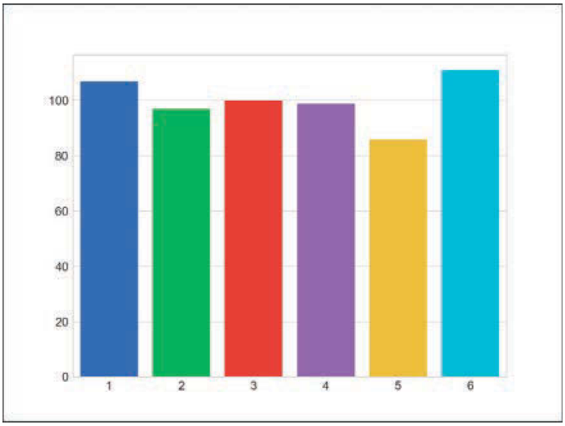
displays the number with *thousands separators*—so, 60000 would be displayed as 60,000.

By default, Seaborn plots graphs on a plain white background, but it provides several styles to choose from (`'darkgrid'`, `'whitegrid'`, `'dark'`, `'white'` and `'ticks'`). Snippet

[1] We'll run a performance comparison in Chapter 7 where we discuss `ndarray` in depth.

[8] specifies the 'whitegrid' style, which displays light-gray horizontal lines in the vertical bar plot. These help you see more easily how each bar's height corresponds to the numeric frequency labels at the bar plot's left side.

Snippet [9] graphs the die frequencies using Seaborn's **barplot function**. When you execute this snippet, the following window appears (because you launched IPython with the --matplotlib option):



Seaborn interacts with Matplotlib to display the bars by creating a Matplotlib **Axes** object, which manages the content that appears in the window. Behind the scenes, Seaborn uses a Matplotlib **Figure** object to manage the window in which the Axes will appear. Function barplot's first two arguments are ndarrays containing the *x*-axis and *y*-axis values, respectively. We used the optional palette keyword argument to choose Seaborn's predefined color palette 'bright'. You can view the palette options at:

```
https://seaborn.pydata.org/tutorial/color_palettes.html
```

Function barplot returns the Axes object that it configured. We assign this to the variable axes so we can use it to configure other aspects of our final plot. Any changes you make to the bar plot after this point will appear *immediately* when you execute the corresponding snippet.

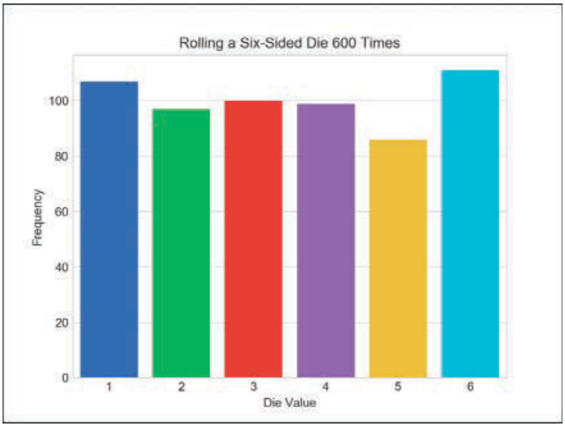
Setting the Window Title and Labeling the *x*- and *y*-Axes

The next two snippets add some descriptive text to the bar plot:

```
In [10]: axes.set_title(title)
Out[10]: Text(0.5,1,'Rolling a Six-Sided Die 600 Times')

In [11]: axes.set(xlabel='Die Value', ylabel='Frequency')
Out[11]: [Text(92.6667,0.5,'Frequency'), Text(0.5,58.7667,'Die Value')]
```

Snippet [10] uses the axes object's **set_title** method to display the title string centered above the plot. This method returns a Text object containing the title and its *location* in the window, which IPython simply displays as output for confirmation. You can ignore the Out[]s in the snippets above.

Snippet [11] add labels to each axis. The **set** method receives keyword arguments for the Axes object's properties to set. The method displays the xlabel text along the *x*-axis, and the `ylabel` text along the *y*-axis, and returns a list of `Text` objects containing the labels and their locations. The bar plot now appears as follows:



Finalizing the Bar Plot

The next two snippets complete the graph by making room for the text above each bar, then displaying it:

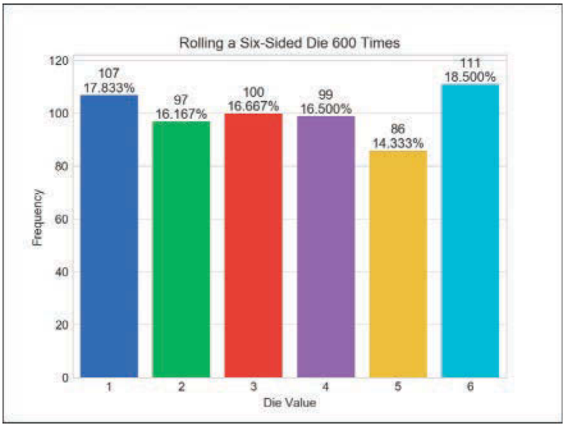
```
In [12]: axes.set_ylim(top=max(frequencies) * 1.10)
Out[12]: (0.0, 122.10000000000001)

In [13]: for bar, frequency in zip(axes.patches, frequencies):
    ...:     text_x = bar.get_x() + bar.get_width() / 2.0
    ...:     text_y = bar.get_height()
    ...:     text = f'{frequency:,}\n{frequency / len(rolls):.3%}'
    ...:     axes.text(text_x, text_y, text,
    ...:               fontsize=11, ha='center', va='bottom')
    ...:
```

To make room for the text above the bars, snippet `[12]` scales the *y*-axis by 10%. We chose this value via experimentation. The `Axes` object's **`set_ylim`** method has many optional keyword arguments. Here, we use only `top` to change the maximum value represented by the *y*-axis. We multiplied the largest frequency by 1.10 to ensure that the *y*-axis is 10% taller than the tallest bar.

Finally, snippet `[13]` displays each bar's frequency value and percentage of the total rolls. The `axes` object's `patches` collection contains two-dimensional colored shapes that represent the plot's bars. The `for` statement uses `zip` to iterate through the `patches` and their corresponding `frequency` values. Each iteration unpacks into `bar` and `frequency` one of the tuples `zip` returns. The `for` statement's suite operates as follows:

- The first statement calculates the center *x*-coordinate where the text will appear. We calculate this as the sum of the bar's left-edge *x*-coordinate (`bar.get_x()`) and half of the bar's width (`bar.get_width() / 2.0`).
- The second statement gets the *y*-coordinate where the text will appear—`bar.get_y()` represents the bar's top.
- The third statement creates a two-line string containing that bar's frequency and the corresponding percentage of the total die rolls.

- The last statement calls the `Axes` object's **`text`** method to display the text above the bar. This method's first two arguments specify the text's *x–y* position, and the third argument is the text to display. The keyword argument `ha` specifies the *horizontal alignment*—we centered text horizontally around the *x*-coordinate. The keyword argument `va` specifies the *vertical alignment*—we aligned the bottom of the text with at the *y*-coordinate. The final bar plot is shown below:



Rolling Again and Updating the Bar Plot—Introducing IPython Magics

Now that you've created a nice bar plot, you probably want to try a different number of die rolls. First, clear the existing graph by calling Matplotlib's **`cla`** (clear axes) function:

```
In [14]: plt.cla()
```

IPython provides special commands called **magics** for conveniently performing various tasks. Let's use the **`%recall` magic** to get snippet `[5]`, which created the `rolls` list, and place the code at the next `In []` prompt:

```
In [15]: %recall 5

In [16]: rolls = [random.randrange(1, 7) for i in range(600)]
```

You can now edit the snippet to change the number of rolls to `60000`, then press *Enter* to create a new list:

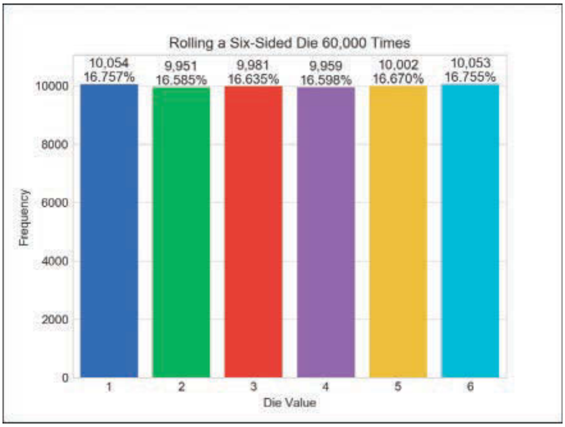
```
In [16]: rolls = [random.randrange(1, 7) for i in range(60000)]
```

Next, recall snippets `[6]` through `[13]`. This displays all the snippets in the specified range in the next `In []` prompt. Press *Enter* to re-execute these snippets:

```
In [17]: %recall 6-13

In [18]: values, frequencies = np.unique(rolls, return_counts=True)
    ...: title = f'Rolling a Six-Sided Die {len(rolls):,} Times'
    ...: sns.set_style('whitegrid')
    ...: axes = sns.barplot(x=values, y=frequencies, palette='bright')
    ...: axes.set_title(title)
    ...: axes.set(xlabel='Die Value', ylabel='Frequency')
    ...: axes.set_ylim(top=max(frequencies) * 1.10)
```

```
   ...: for bar, frequency in zip(axes.patches, frequencies):
   ...:     text_x = bar.get_x() + bar.get_width() / 2.0
   ...:     text_y = bar.get_height()
   ...:     text = f'{frequency:,}\n{frequency / len(rolls):.3%}'
   ...:     axes.text(text_x, text_y, text,
   ...:               fontsize=11, ha='center', va='bottom')
   ...:
```

The updated bar plot is shown below:



Saving Snippets to a File with the %save Magic

Once you've interactively created a plot, you may want to save the code to a file so you can turn it into a script and run it in the future. Let's use the **%save magic** to save snippets 1 through 13 to a file named `RollDie.py`. IPython indicates the file to which the lines were written, then displays the lines that it saved:

```
In [19]: %save RollDie.py 1-13
The following commands were written to file `RollDie.py`:
import matplotlib.pyplot as plt
import numpy as np
import random
import seaborn as sns
rolls = [random.randrange(1, 7) for i in range(600)]
values, frequencies = np.unique(rolls, return_counts=True)
title = f'Rolling a Six-Sided Die {len(rolls):,} Times'
sns.set_style("whitegrid")
axes = sns.barplot(values, frequencies, palette='bright')
axes.set_title(title)
axes.set(xlabel='Die Value', ylabel='Frequency')
axes.set_ylim(top=max(frequencies) * 1.10)
for bar, frequency in zip(axes.patches, frequencies):
    text_x = bar.get_x() + bar.get_width() / 2.0
    text_y = bar.get_height()
    text = f'{frequency:,}\n{frequency / len(rolls):.3%}'
    axes.text(text_x, text_y, text,
              fontsize=11, ha='center', va='bottom')
```

Command-Line Arguments; Displaying a Plot from a Script

Provided with this chapter's examples is an edited version of the RollDie.py file you saved above. We added comments and a two modifications so you can run the script with an argument that specifies the number of die rolls, as in:

```
ipython RollDie.py 600
```

The Python Standard Library's **sys module** enables a script to receive *command-line arguments* that are passed into the program. These include the script's name and any values that appear to the right of it when you execute the script. The sys module's **argv** list contains the arguments. In the command above, argv[0] is the *string* 'RollDie.py' and argv[1] is the *string* '600'. To control the number of die rolls with the command-line argument's value, we modified the statement that creates the rolls list as follows:

```
rolls = [random.randrange(1, 7) for i in range(int(sys.argv[1]))]
```

Note that we converted the argv[1] string to an int.

Matplotlib and Seaborn do not automatically display the plot for you when you create it in a script. So at the end of the script we added the following call to Matplotlib's **show** function, which displays the window containing the graph:

```
plt.show()
```

5.18 Wrap-Up

This chapter presented more details of the list and tuple sequences. You created lists, accessed their elements and determined their length. You saw that lists are mutable, so you can modify their contents, including growing and shrinking the lists as your programs execute. You saw that accessing a nonexistent element causes an IndexError. You used for statements to iterate through list elements.

We discussed tuples, which like lists are sequences, but are immutable. You unpacked a tuple's elements into separate variables. You used enumerate to create an iterable of tuples, each with a list index and corresponding element value.

You learned that all sequences support slicing, which creates new sequences with subsets of the original elements. You used the del statement to remove elements from lists and delete variables from interactive sessions. We passed lists, list elements and slices of lists to functions. You saw how to search and sort lists, and how to search tuples. We used list methods to insert, append and remove elements, and to reverse a list's elements and copy lists.

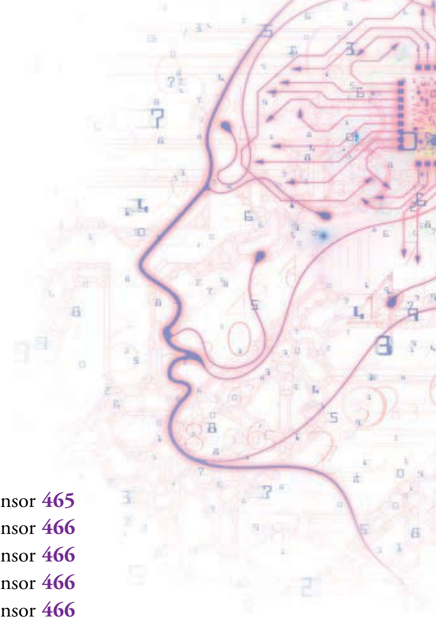
We showed how to simulate stacks with lists. We used the concise list-comprehension notation to create new lists. We used additional built-in methods to sum list elements, iterate backward through a list, find the minimum and maximum values, filter values and map values to new values. We showed how nested lists can represent two-dimensional tables in which data is arranged in rows and columns. You saw how nested for loops process two-dimensional lists.

The chapter concluded with an Intro to Data Science section that presented a die-rolling simulation and static visualizations. A detailed code example used the Seaborn and Matplotlib visualization libraries to create a *static* bar plot visualization of the simulation's final results. In the next Intro to Data Science section, we use a die-rolling simulation with a *dynamic* bar plot visualization to make the plot "come alive."

In the next chapter, “Dictionaries and Sets,” we’ll continue our discussion of Python’s built-in collections. We’ll use dictionaries to store unordered collections of key–value pairs that map immutable keys to values, just as a conventional dictionary maps words to definitions. We’ll use sets to store unordered collections of unique elements.

In the “Array-Oriented Programming with NumPy” chapter, we’ll discuss NumPy’s `ndarray` collection in more detail. You’ll see that while lists are fine for small amounts of data, they are not efficient for the large amounts of data you’ll encounter in big data analytics applications. For such cases, the NumPy library’s highly optimized `ndarray` collection should be used. `ndarray` (*n*-dimensional array) can be much faster than lists. We’ll run Python profiling tests to see just how much faster. As you’ll see, NumPy also includes many capabilities for conveniently and efficiently manipulating arrays of *many* dimensions. In big data analytics applications, the processing demands can be humongous, so everything we can do to improve performance significantly matters. In our “Big Data: Hadoop, Spark, NoSQL and IoT” chapter, you’ll use one of the most popular high-performance big-data databases—MongoDB.[2]

[2] The database’s name is rooted in the word “humongous.”



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